Bricks and Artificial Stones of Non Plastic Materials

Their Manufacture and Uses

A. B. SEARLE

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THEIR MANUFACTURE AND USES

PUBLIC BUILDING OF LIME-SAND BRICKS
Courtesy of Sutcliffe, Speakman & Co. Ltd.

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BY

ALFRED B. SEARLE

LECTURER ON BRICKMAKING UNDER THE CANTOR BEQUEST
AUTHOR OF "THE CLAYWORKER'S HANDBOOK" "MODERN BRICKMAKING" "BRITISH CLAYS, SHALES & SANDS" "CEMENT, CONCRETE AND BRICKS," Etc. Etc.

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PREFACE

THE purpose of this book is twofold : (*a*) to supply reliable and unbiased information to those firms and individuals who contemplate making or buying bricks and artificial stones from non-plastic materials ; (*b*) to assist manufacturers in solving the problems which occur in the course of their work, to enable them to remedy defects and to avoid other technical difficulties.

The following pages embody the chief results of the author's own investigations and experiences, as well as that of a considerable number of manufacturers and others, and are arranged in such a manner as to enable readers to find the information they require, with the least possible amount of trouble.

The author has too large a knowledge of clay bricks and terra-cotta to underrate their value, but the fact must not be overlooked that in various parts of the United Kingdom, and even more so in the British Colonies and Dependencies, there are large areas where no suitable clays are available and where the difficulty and cost of using the large quantities of coal needed to heat the kilns is prohibitive to the manufacture of plastic bricks and blocks. In some instances (*see* p. 135) the cost of the removal of overlying sand may be converted into a profit by making such sand into bricks. Moreover, the skill required in the burning of clay products is very great, and men of sufficient ability are not always obtainable where building materials are required. Hence, in such localities, in starting new collieries, town-planning schemes, the construction of extensive works, and in tropical and Colonial work, the advantages and disadvantages of the use of non-plastic materials should always be considered, particularly where sand, clinker, or slag is abundant. This consideration must be careful and thorough, and it should only be undertaken by men competent for the work ; for ignorance, bias, and guesswork form some of the most prolific causes of failure in the production of non-plastic bricks. Many men—particularly on the Continent and in the United States—have bought machinery and started to make lime-sand bricks without any actual knowledge of what a really good brick should be, and often without knowledge of how to distinguish good bricks from bad ones. They have been told that they could make good bricks if they bought the right machinery, and are greatly surprised and disappointed when their product is not up to the standard demanded by architects and builders. Had such men relied more on competent and impartial expert advice and less on their own opinions and on the statements of unscrupulous people with "something to sell," most of their failures would have been avoided. Where reliable advice is not readily obtainable, it is hoped that the following pages will enable prospective manufacturers to avoid the chief pitfalls into which others have fallen and to find the best methods of procedure, suitable modifications being made to meet local needs and requirements.

With the exception of an air-separator, and some of the machines used for concrete bricks and tiles, all the machinery is of British manufacture, as the author has found from experience that strength of construction, rather than ingenuity of design, is the chief requirement in machinery used in the manufacture of bricks and artificial stones. Moreover, this is essentially a British industry, and although the author has made an exceedingly thorough study of all the chief Continental machinery used for such bricks and stones as are here described, he has failed to find any important feature in which such foreign machinery is superior to that of British manufacture. Foreign machines have only been described when, so far as the author is aware, similar machines are not made in Great Britain. Many foreign machines, the advertisers of which publish flamboyant claims, have been found by the author, on careful examination, to be distinctly inferior to the corresponding machines made in Great Britain. It is scarcely necessary to point out that such claims, made without anything to substantiate them, should not be too readily accepted without further proof.

For the readiness with which they have assisted him in the loan of illustrations and in other ways, the author is grateful to Mr. E. R. Sutcliffe (Messrs. Sutcliffe, Speakman & Co., Leigh, Lancs), to Mr. H. Alexander (Messrs. H. Alexander & Co. Ltd., Leeds), Messrs. Gebr. Pfeiffer (Kaiserslautern), and Mr. R. H. Baumgarten (Lewisham).

The author also expresses his thanks to numerous business friends and clients for useful suggestions and to various members of his staff—especially Mr. J. W. Merchant, and Mr. H. Lindop for assistance in preparing this book for the Press, and to Mr. E. R. Bradforth, for reading the proofs and preparing the Index.

ALFRED B. SEARLE.

The White Building, Sheffield.

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BRICKS AND ARTIFICIAL STONES OF NON-PLASTIC MATERIALS

CHAPTER I

KINDS OF BRICKS AND STONES

To many minds the word *brick* suggests an article made of burned clay, but this is by no means the only substance of which bricks are made. For instance, the linings of furnaces for melting steel are largely composed of bricks made by crushing a pure silica rock to powder, re-shaping it with the addition of milk of lime and then burning at a temperature of about 1500° C. Such *silica bricks* or *Dinas bricks* are capable of withstanding very high temperatures and for some purposes are even preferred to bricks made of the most refractory fireclay.

Bricks for building purposes may be made of a similar material, though it is usual to employ sand instead of crushed rock, and to modify the mode of manufacture. Such bricks are termed *lime-sand bricks* or *sand-lime bricks* on account of the materials used in their production.

Instead of sand, other materials may be used, such as the clinkers from refuse destructors (*clinker bricks*), slag (*slag bricks*), crushed rock, etc., the essential feature of each being the presence of a sufficient amount of a material which will combine with the lime to form hard, strong, and durable bricks.

The characteristics of the bricks made of these various materials differ in many ways from each other and from the bricks made of clay; their distinguishing features are described on the following pages.

The widespread deposits of clays suitable for making bricks have largely prevented the advantages of bricks made of sand and other non-plastic materials from being appreciated, and the former have gained a wide popularity on account of their familiarity. In many localities, however, clays are scarce or unsuitable, whereas non-plastic materials are abundant, so that their use instead of clay is highly convenient and profitable.

Moreover, the irregularities in shape, size, and colour of bricks made of burned clay form a serious drawback to their use for many purposes, whilst the cost of manufacture and the expense and uncertainty attending the use of kilns render the manufacture of bricks from clay a precarious business except in skilled hands. Bricks made from sand and other non-plastic materials avoid the use of kilns and so affect a considerable saving.

The manufacture of bricks from a mixture of sand and lime has proved highly successful in many localities, particularly in Germany, Austria, the United States, and in several British colonies. In Great Britain itself the low prices at which clay bricks are sold limits the manufacture of lime-sand bricks to those localities where sand is plentiful and clay is scarce or unsuitable. Some idea of the great popularity of lime-sand bricks may be gained from the following figures :

Annual Output of Lime-Sand Bricks.

Germany	1,000,000,000
Berlin alone	400,000,000
United States	400,000,000
Sweden	200,000,000
United Kingdom and British Colonies	80,000,000

Lime-sand bricks were first patented in 1880 by Dr. W. Michaelis, whose discovery of the hardening mixtures of lime and silica by means of compressed steam was rapidly followed by the granting of other patents. At first, the processes of manufacture were highly complex and frequently led to great disappointments, but gradually the initial difficulties were overcome and lime-sand bricks have now been manufactured in large quantities on a commercial scale for about twenty years.

Briefly, the method now chiefly used consists in preparing a mixture of sand, lime, and water and pressing this into the shape of bricks. These bricks are then hardened by heating in an autoclave containing steam under pressure. The bricks are then ready for use but improve with keeping.

Clinker bricks and *slag bricks* are of more recent origin, but bricks made from granulated slag have been made on the Continent for more than twenty years. Clinker bricks are made from the clinker or ashes obtained from refuse destructors and to a lesser extent from boilers. Both clinker and slag bricks have proved equally successful in localities where clinker or slag is available in large quantities. The colour of these bricks is less attractive than that of lime-sand bricks, but this is of minor importance in many cases, whilst the strength of well-made clinker and slag bricks is all that can be desired.

These bricks are usually made in a manner similar in general principle to that used for lime-sand bricks, but sometimes they are cast from molten slag. For instance, at Middlesbrough, slag bricks are made by receiving the molten slag in specially constructed cars which take it to a large revolving table provided with moulds of cast iron. The fluid slag is run into these moulds so as to fill each in turn. As they cool, the bricks are taken from the moulds and are annealed in a series of brick-work chambers where they remain until quite cold. Such bricks are hard and heavy, glassy in structure, cream-coloured externally, and blue on fracture. They are used for paving purposes, especially for street crossings, while curbs and channels are also cast. Unfortunately they often contain bubbles, but they are absolutely impervious to moisture and admirably suited to resist wear. The moulding is rough and many of the bricks are spoilt in manufacture. Consequently the manufacture is of small importance compared with that of bricks made of granulated or ground slag in a manner similar to lime-sand bricks.

Bricks made of *crushed rock* (chiefly quartzose) were originally produced by Frederick Ransome in 1860, or twenty years before Michaelis' invention of the hardening chamber. The crushed quartz, consisting of grains of various sizes, is mixed with such a quantity of water-glass that one part of soluble silica is added to eighteen parts of quartz. The pasty mass is moulded to shape and then immersed for several weeks in a solution of calcium chloride and the hardened brick or block is then washed in running water until all the soluble salts have been removed. The calcium chloride decomposes the water-glass (sodium silicate) forming a calcium silicate of complex composition, together with common salt. The latter is removed by washing the stone. The calcium silicate acts as the bond or hardening agent.

Ransome's stone made in this manner has a crushing strength of 7000 to 12,000 lb. per sq. in., but the process never became commercially profitable, though it has been revived in various forms at different times. The chief objections to it are the incompleteness of the reaction between the calcium chloride and the water-glass—especially in the centre of the blocks or bricks—and the impossibility of washing out all the salt produced. The residual salt is slowly removed by rain but gives the buildings in which such blocks or bricks are used an unpleasant aspect. Ransome's stone constitutes a kind of ideal artificial stone by which others made in a cheaper and more rapid manner may be judged.

Other artificial stones are described in Chap. IX.

CHAPTER II

THE RAW MATERIALS

It is convenient to collect information respecting all the raw materials into a single chapter, though these materials will not all be used at the same time.

Bricks made of non-plastic materials consist of two essential ingredients :

(*a*) The non-plastic particles such as sand, crushed slag, ground ashes (*clinker*), etc.

(*b*) The binding material, such as lime.

Sand is by far the most widely used ingredient of lime-sand bricks and must be obtained locally if the works are to be a success. The lime may be brought from a distance, but the sand must be at hand.

Sand is chiefly composed of silica, the best sands for the purpose consisting almost exclusively of grains of quartz, though the presence of a considerable proportion of other materials is unimportant, providing that the grains are all covered with silica. Thus, a series of sand grains each with a core of other material may prove quite satisfactory, whilst an equal number of purer sand grains of similar sizes, but containing grains of other substances alongside the particles of sand, would be useless for brick manufacture. Hence, the chemical composition of a sand, as shown by analysis, is of far less importance than the physical conditions of the various constituents.

So far as *chemical composition* is concerned, the ideal sand is one in which every grain can be completely covered with lime, and in which the whole of the lime comes into direct contact with silica. This does not necessarily mean that the sand grains must consist exclusively of pure silica, so long as the impurities are inside the grains, and do not form complete grains themselves. Thus, it is possible to use a sand composed of an entirely non-siliceous material provided the grains are covered with a film of silica. Such a sand would be low in silica, and yet would give excellent results as the proportion of silica in a sand does not necessarily indicate its value for making lime-sand bricks.

Hence, all sources of sand are equally available—pits, river beds, sea-shores, dunes, etc., though the sands from some of these sources are more suitable than others on account of their purity and sharpness.

The statement is sometimes made that felspathic sands are superior to pure quartz sands. This is based on the mistaken assumption that the felspar can combine more easily with the lime. As stated on a later page, nothing can be better than a quartz sand, the soluble silica theory having been exploded by experimental data.

In some sands the impurities are in the form of extremely minute grains which are arranged in the voids or spaces between the larger grains, and so long as the latter are properly coated with lime the effect of the smallest grains of impurities may frequently be neglected. Before a sand of this kind is used, however, it should be fully tested by an expert; otherwise, serious trouble may arise.

The difference between good and bad sand grains is shown diagrammatically in Figs. 1 and 2. In Fig. 1 the impurities (shown black) are in the centre of the sand grains, whilst in Fig. 2 the impurities form separate grains lying between the particles of sand.

Tests of several sands of a low percentage of silica have shown that bricks of more than normal strength may be readily obtained with them. Nevertheless, it is only natural that a pure or highly siliceous sand will be preferred to one which is less pure when both are equally available. It usually happens that impure sands contain the bulk of the impurities as irregularly distributed grains of various minerals and this renders them unsuitable for the manufacture of lime-sand bricks. Grains of undesirable minerals which are completely covered by a coating of silica are comparatively rare, but their value must not be misjudged as the result of an incomplete investigation, such as a chemical analysis unaccompanied by other tests.

FIG. 1. Good sand grains

FIG. 2. Bad sand grains

From the foregoing statements it will be understood that the proportion of silica in a sand—this being the factor upon which the purity of the material is usually based—gives but little guidance in deciding whether a given sand will be satisfactory for the manufacture of lime-sand bricks. It is an established fact that many sands which have been regarded as useless on account of their low silica content are really excellent for making lime-sand bricks, as their impurities are, fortunately, completely enveloped by a coating of silica and so are rendered innocuous.

An objection is sometimes raised to certain forms of sand or crushed rock which are largely destitute of "soluble silica," that is to say, of silica in such a form that it can be readily dissolved by a strong solution of caustic soda. It is true that the strength of a lime-sand brick is largely dependent on the proportion of silica which combines with the lime, and that it would appear that any form of silica which can combine with lime with special ease should, therefore, be a desirable constituent, but in actual practice it is found that the presence of soluble silica is by no means essential, and its absence can be fully compensated by the use of some sand in a sufficiently finely ground condition for it to be readily attacked by the lime.

Experiments made by the present writer some years ago showed quite conclusively that pure sands which showed no soluble silica whatever when treated with caustic soda solution, were found to yield 5 per cent. or more when made into lime-sand bricks. In other words, the lime, under the conditions of manufacture, was able to deal with the insoluble silica in order to produce a calcium silicate quite as effectively as when the silica was in a more soluble form. It is, however, important to notice that in these experiments a sufficient proportion of the sand was present in the form of the finest possible flour. When only coarse sand grains were used the lime did not combine so readily, and with sand grains of pure quartz, which were sufficiently large to be retained on a sieve with thirty-six holes per linear inch, but which passed through one with twenty-five holes, practically no combination occurred even when the bricks were exposed for three times the usual period to the action of steam under pressure.

It was at one time thought that a high percentage of soluble silica was essential to a successful manufacture of lime-sand bricks, but, as explained above, this idea is erroneous. Providing that there is a sufficient number of grains of extreme smallness for them to combine readily with the lime during the steaming process, the proportion of soluble silica is unimportant. The necessity of having sufficiently small grains has long been known to certain manufacturers, who have regarded this fact as a secret of considerable importance, though it should be obvious that as chemical action always takes place most completely when the particles of the substances are in the most intimate contact, the fullest combination of lime and silica will be effected when both are extremely well ground. The cost of grinding the whole of the sand to an impalpable flour would be prohibitive, and, indeed, it is unsatisfactory, but with most sands it is essential that a certain proportion should be reduced to a fine dust.

Some sands naturally contain a sufficiency of fine flour, and need no special grinding.

If the sand is properly graded so that the voids are at a minimum, there will necessarily be a sufficient proportion of these very fine grains.

It is very interesting to study the various other forms of finely divided silica which various firms employ in order to secure a sufficient combination between the sand and the lime. Many of these are the result of working on the plan so long used by Edison: "Try everything, likely and unlikely, to see if you can get any improvement." The most successful additions which have been made in this way are, all of them, forms of finely ground silica, produced either naturally or artificially. Thus, "Potter's Flint" is typical of an artificially ground silica of great fineness, and "Kieselguhr" and "Infusorial Earth" are equally typical natural forms of fine silica. They are useful, but costly, and their place can be equally well taken by the ordinary sand, providing that this is sufficiently finely ground.

The influence of *clay* in the sand used for lime-sand bricks is very difficult to ascertain. Some manufacturers have condemned it as detrimental whilst others have found the addition of 2 or 3 per cent. of clay to a perfectly clean sand to be an advantage. One cause of this difference may be the crude method used for determining the amount of clay present. For instance, if the sand is washed, there will be removed a considerable quantity of extremely fine grains of sand as well as any clay present, so that it is incorrect to regard the whole of the washed-out material as clay. Moreover, the removal of these fine grains of silica may be harmful to the sand, and the substitution of a corresponding quantity of equally small grains of clay may largely restore the sand to its original condition or may supply it with grains of the requisite fineness if these were previously lacking.

On the other hand, the addition of a highly plastic clay may smear the grains of sand and prevent the lime attacking them, thereby proving a harmful instead of a valuable addition, especially in a sand which already contains a sufficient proportion of fine grains.

One fact must not be overlooked, viz. the smallness of the clay particles causes them to combine more readily with the lime than do the coarser sand grains, so that if there is more clay than the lime can neutralize, the brick will be weak. In other words, if the amount of clay present in the sand, or added to it, is increased, the amount of lime must be correspondingly increased. This logical deduction has been confirmed by the experiments of Michaelis and, independently, by those of Glasenapp.

As the sole purpose of any clay present is to take the place of any equally small grains of silica, it is clear that a sand containing more clay than is necessary for this purpose must be washed before use. Coarse sands, on the contrary, must be supplied with the requisite amount of fine particles ; these may be formed by grinding a portion of the sand very fine and mixing it with the remainder or (less satisfactorily) by adding a small quantity of clay. Hence, the only object of adding clay to a sand which requires it, is to supply the necessary fine particles ; these are far more satisfactorily supplied by grinding some of the sand in a manner to be described later. The *salt* in sea-sand does not appear to do any harm providing that the sand has been well washed by the rain, as is the case with dune-sand. Sand dug directly from the shore should be avoided ; bricks made from it are liable to become scummed and to remain moist. That these drawbacks are not necessarily serious is shown by the fact that at least one works known to the author has regularly used sea-sand for some years and no complaints as to the quality of the bricks have ever been made.

Iron compounds in the sand may affect the colour of the bricks, but a white sand, though advantageous, is not essential, as the treatment with lime makes the colour of dark sand rather lighter.

The *shape of the grains* of sand is, in some respects, more important than their composition. The most suitable grains are round or angular and not flat or flaky like mica. Plate-like grains are not satisfactory as they lie too closely on each other and have a tendency to slip or shear under pressure.

Relative sharpness or roundness of grain is of far less importance than accurate grading, *i.e.* the correct proportions of grains of different sizes, and repeated tests made by the author have shown that a sand with rounded grains often gives better results than a sharp sand (both being equally well graded) because the rounded grains have fewer voids and make denser bricks.

Rounded grains also roll more easily into the voids than do sharper grains so that, while the latter may interlock more perfectly in some cases, they produce a sand with more voids and therefore tend, in practice, to make a weaker brick than a sand with rounded grains. Owing to the larger proportion of voids, sharp sands require more lime than rounded sands.

Sharp, angular grains are, however, the most generally suitable for brick making. *Dune sand* and *pit sand* are sometimes composed of grains which are so rounded that they are difficult to use. By grinding 25 per cent. of the sand, a sufficient proportion of sharp material may often be produced from an otherwise unsuitable one. This is one reason why Method D (Chap. V) has proved so valuable with sands which are, otherwise, difficult to use.

The *sizes of grains* of sand are of very great importance. It is not sufficient to have all the grains of one size ; on the contrary, there must be several different ones in order that there may be a satisfactory, but not excessive, proportion of voids or interstices between the particles.

The ideal sand—as far as the size of grain is concerned—is one in which the spaces between the larger grains are filled by the smaller particles and the spaces between the latter are occupied by still smaller grains, and so on, the smallest grains just passing through a sieve with 200 holes per linear inch. The spaces left between the finest particles of sand ought to be so small that when each grain is covered by a film of lime, at a later stage in the manufacture, there will be scarcely any voids left.

There is good reason to suppose that it is the smallest grains of sand which combine most readily with the lime, so that sufficient of these must be present, but an excess must be avoided as very fine grains do not interlock so well as grains of different sizes and so produce a weaker brick.

Generally speaking, the whole of the sand used should pass through a sieve having twenty holes per linear inch and about 10 per cent. of it should pass through a sieve having 150 holes per linear inch.

Grains which pass readily through a sieve with 200 holes per linear inch are usually so contaminated with clay that they should be removed by washing, unless the proportion of such grains is less than 4 or 5 per cent., when they will usually do so little harm that washing becomes unnecessary.

Flour sand consists of grains of sand which are so small that they will pass completely through a sieve with 200 holes per linear inch. In practice such sand is sufficiently fine if it does not leave more than 20 per cent. residue on such a sieve. The proportion of flour sand needed in the material used for lime-sand bricks depends upon the sizes of the other grains. Usually it amounts to about 15 per cent. of the whole sand, but the correct amount must be found in each case by experiment.

Flour sand may be most satisfactorily produced by grinding coarser sand in a ball-mill. One type of mill which has proved particularly satisfactory for this purpose is the tube mill shown in Fig. 16.

Grading the sand is often necessary if the strongest bricks are to be obtained.

This treatment consists in first testing the sand on a number of sieves and ascertaining the proportion of grains of (say) five different sizes, and afterwards adding other grains so as to make the whole of the sand of a suitable composition and texture. When once the correct proportions of each of the agreed sizes have been ascertained for any particular sand it is only a matter of testing the sand at suitably frequent intervals in order to be sure that the correct proportions are maintained in the works.

Fortunately for the manufacturer, most sands contain grains of so many sizes that they already exist in a sufficiently graded form. Were this not the case the cost of manufacture of lime-sand bricks would be greatly increased. It is, however, desirable that all sands should be tested from time to time to ensure their being of a suitable grade, as otherwise trouble may ensue.

In one works with which the author is acquainted no attempt was made to grade the material, with the result that pieces of clay and stone as large as filberts could be found in some of the bricks and naturally reduced their quality to a serious extent.

If, after testing a number of sands, the results are plotted on a chart with the size of the openings of the various sieves as abscissæ, and the percentage of particles of less than a given diameter as ordinates, that sand will produce the best bricks which gives the roundest and smoothest curve. If all the grains are of the same size there will be no grading at all, and the " curve " will be a vertical straight line ; such a sand is of small value for making lime-sand bricks.

Wholly fine sands have a far larger surface of grain to be covered with lime than have coarser sands ; they also contain a large volume of air which it is extremely difficult to displace. Moreover, they tend to be badly graded within the limits of size of grains present and require more lime than coarser sands without any corresponding advantages. Such fine sands are greatly improved by mixing with a coarse sand or with crushed rock of similar composition.

Voids. As previously explained, the object of grading the sand is to secure a proper interlocking of the grains and a suitable proportion of voids or interstices between the grains of sand. If the voids are too numerous the bricks will be weak, because there will not be a sufficient number of points of contact between the particles to give the necessary strength. It is true that the lime, being in an exceedingly fine powder, and, to some extent, in the form of a solution, will penetrate into these pores, and will, later, fill them to a certain extent, but the filling can only occur within very narrow limits, and too many or too large voids will prevent the necessary contact between the particles, even after the addition of lime.

The proportion of voids or " spaces " is greatest when the sand grains are coarsest, and least when they are finest. This may readily be shown by taking an extreme case, and using various sizes of shot, or balls from ball-bearings, in place of the sand. The relative proportion of the voids will then be clearly visible to the eye, and the necessity of having a sufficient number of small-sized grains will be apparent.

It does not necessarily follow that the best results accompany the least proportion of voids, for ample room must be left for the lime and water; the lime-sand brickmaker must, therefore, ascertain by trial what is most suited to his needs.

The proportion of "voids" in a sand may be determined in a variety of ways, one of the simplest and best being as follows: A glass tube or cylinder graduated in cubic centimetres (c.c.), is filled with water exactly to the 20 c.c. mark, and exactly 10 c.c. of the sand is placed in another similar cylinder, and is then poured carefully into the water, or if it is too damp the water is poured on to the sand. After a little shaking to secure the complete admixture of the sand and water, the two are allowed to rest, when it will be found that the volume of sand and water (*c*) will be higher than the 20 c.c. mark (*a*), but will be lower than the 30 c.c. mark (*d*), unless the material contained absolutely no voids; the rise in the level of the water above the mark (*a*) will give the true volume of the sand, apart from the voids, and this, deducted from 10 and the difference multiplied by 10, will give the percentage of voids in the sand. Or, if preferred, the difference between the water-level after the sand has been added, and 30 multiplied by 10 will give the percentage of voids in the sand.

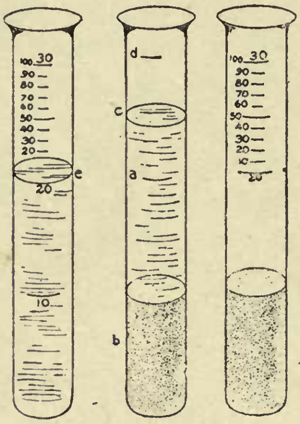


FIG. 3. Ascertaining the Proportion of Voids

Thus, if the water in the tube containing both sand and water stood at the half-way point between 28 and 29 c.c. (*i.e.* at $28\frac{1}{2}$ c.c.), the percentage of voids can be calculated (i) by deducting 20 from $28\frac{1}{2} = 8\frac{1}{2}$, the rise of the water above the 20 c.c. level, and deducting this from 10 and multiplying the result by 10, viz. $10 - 8\frac{1}{2} = 1\frac{1}{2}$, which $\times\ 10 = 15$ per cent., or (ii) deducting the $28\frac{1}{2}$ from 30 gives $1\frac{1}{2}$, which multiplied by $10 = 15$ per cent. of "voids." As will be seen, the second method is usually the easier of the two.

In order that the results may be sufficiently accurate, certain precautions are necessary. In the first place, the tubes should not be more than half an inch internal diameter, and it is better if they are less. In the second place, they should be marked in tenths between *a* and *d*, so that the measurement of the water-level may be very accurately made, and the error introduced by the multiplication be as small as possible. Finally, it is necessary that *all* the sand and all the water shall be present in the tube in which the final measurement is affected. If one or two drops of water or a few grains of sand remain in the other cylinder, the error thus caused may be serious. For this reason it is often better to put more than the 20 c.c. of water into the first tube, to notice exactly the volume it occupies, and then to pour about 20 c.c. into the tube containing the sand. The exact volume of water thus used may be found very accurately by reading the volume of water left in the first tube and deducting this from that originally present. This does not affect the calculation materially, except that the volume of the water used must be substituted for the figure 20 in calculation (i), and a number formed by adding 10 c.c. to the volume of water used must be substituted for 30 in calculation (ii).

The smaller the proportion of voids in a sand the better it is for most lime-sand bricks. The percentage of voids should not be less than 8 nor more than 20 except under most unusual conditions.

Washing is generally advisable if the sand contains more than 2 or 3 per cent. of clay, but in some instances it is not really necessary. For instance, when bricks are made by a firm solely for their own use for inside or foundation work it would seldom be necessary to wash the sand, and instances are known of satisfactory bricks made of sand containing as much as 20 per cent. of clay. Usually, however, washing is desirable unless the sand is quite clean.

Unfortunately, the washing also removes some of the finest grains of sand, but as this cannot be avoided the latter must be replaced by the addition of a suitable proportion of sand ground specially for the purpose. Washing is costly, even under the most favourable conditions, and if two sands are available, the one which does not require washing should be preferred.

Grinding is only necessary when the sand does not occur in a suitably graded condition. The proportion (if any) requiring to be ground will, clearly, depend on the grading of the material. Thus, if the raw material used is a soft sandstone it will be necessary to grind the whole of it, and then to grade and adjust it. Many naturally occurring sands require no adjustment, as all the various sizes of grains are in the correct proportions, but in some cases there is a deficiency in fine grains, and these must usually be obtained by grinding a portion of the sand and adding it to the remainder.

Sandstones differ greatly when ground, some of them forming minute globular grains which have little or no felting or interlocking power, are deficient in "surface" relative to their volume, and are only attacked by lime with difficulty. Such grains are practically useless for lime-sand brickmaking, unless they can be mixed with some other material, in which case they form a cheap diluent rather than a desirable constituent of the bricks.

For crushing sandstone, grit and similar rocks, the most economical and convenient machine is an edge-runner mill (Fig. 4) with a revolving pan perforated with $\frac{1}{4}$-in. holes, or the material may be broken by hammers or by a jaw-crusher until it is sufficiently small to pass through a $\frac{1}{2}$-in. ring.

It is exceedingly important that the material should be fed in as uniform a manner as possible, as otherwise the output of the mill will be reduced.

The product from the mill must usually be passed over a screen having 20 to 30 holes per linear inch, or over a sloping plate having $\frac{1}{8}$-in. holes in it. The coarse material is returned to the mill, and that which passes through the screen is regarded as the "sand," of which the bricks are made. By adjusting the mesh of the screen or the slope of the perforated plate, the size of the particles in the sand may be varied so as to secure a material of a proper grade, though it will usually be deficient in very fine grains. Instead of trying to produce these finest grains with an edge-runner mill, it is better to grind a portion of the sand in a ball-mill as described on p. 30. Some rocks when ground dry are not granular but powdery ; these are useless as they cannot be properly graded. In most cases, this difficulty may be avoided by sprinkling the material with water previous to grinding it or during the grinding.

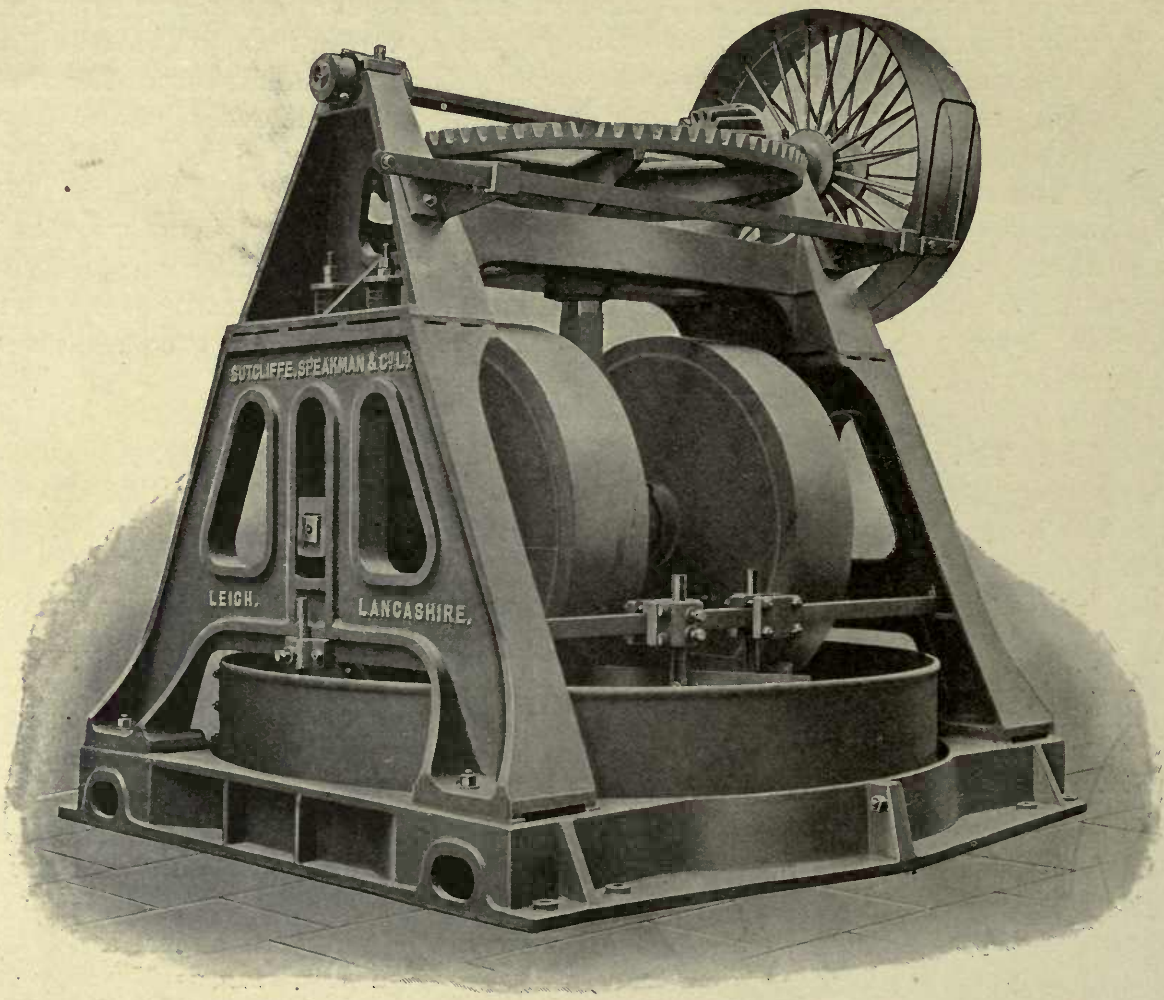


FIG. 4. Edge-runner Mill.

The moist product is usually sufficiently granular to be quite satisfactory for the manufacture of lime-sand bricks.

Screening. If the sand used contains only a small proportion of pebbles or gravel, it is often cheaper to screen it than to grind it. For this purpose it is fed to an elevator (Fig. 5) and from the latter falls on to a sloping steel plate perforated with $\frac{1}{8}$-in. holes, the angle of the plate being adjusted so as to obtain a sand of the requisite fineness. Vibrating screens are only necessary when very wet sands are used, and in such a case it is often cheaper to grind the sand rather than to dry it or screen it.

As already explained, the screening must be so arranged that the screened sand is properly graded; otherwise the sand must be divided into groups according to definite sizes of grains by the use of several screens, and weighed or measured. Quantities of each group must be mixed together in definite proportions in order to secure a properly graded product.

Imperfect screening is likely to lead to serious results. It is seldom satisfactory to attempt to remove the finest particles, including clay, by screening; the sand should be washed, dried, and then screened. The screened material should then be carefully tested and, if necessary, screened a second time.

The *testing of sand* for lime-sand bricks is very important and should be carried out by experts. (Ordinary analytical chemists have neither the necessary appliances nor the special knowledge required.) These tests are especially necessary before starting the works, but they should be repeated at intervals to ensure the quality of the sand being maintained.

FIG. 5. Screen and Lime Measurer
Courtesy of Sutcliffe, Speakman & Co. Ltd.

Most tests are made on samples delivered to the laboratories, no opportunity being allowed for the examination of the deposit or the selection of truly representative samples. The reason for this is chiefly one of cost, and since the condition obtains, the chemist must do the best he can with the sample submitted; but it is always better, and is sometimes cheaper in the long run, to have the analyst collect his own samples from the site.

The following are the tests to which the sample of sand submitted for testing should be subjected:

(1) Determination of the percentage of moisture.
(2) Determination of the percentage of silt.
(3) Chemical analysis to determine silica and content of clay matter.
(4) Loss on ignition.
(5) Determination of the percentage of voids.
(6) Granulometric analysis.

(7) Comparative crushing tests of bricks made from sample sand and re-graded sand, using identical lime.

In making test bricks it is very important that the pressure to which they are subjected should be accurately known. Each material has a pressure at which the best results can be obtained, and unless this is ascertained by a series of tests it is unlikely that bricks of the highest quality will be produced. An unsuitable pressure during manufacture may make all the difference between a good brick and a bad one, or it may result in a good material being condemned.

To the foregoing tests should be added several not usually carried out :

(8) Microscopic examinations, which need not necessarily be exhaustive.

(9) The effect, on strength, of using different limes.

(10) Permeability of resulting bricks.

(11) Weight per cubic foot as received and dried.

(12) Determination of the amount of organic matter contained.

(13) Compression tests on bricks made with varying proportions of lime and water.

Many engineers maintain that in making comparative tests of sand, the same amount of water should be used with each sand, overlooking the fact that in actual work one sand will require more water than another to bring the mixture to the consistency required by the work. We cannot assume the same percentage of water will give the same consistency with two different sands. If this practice is followed, one sand may have too much water and the other too little. In the actual work where the sand is to be used, a paste of a certain consistency will be made with no regard to how much water is needed to obtain it, and in order that the tests may give a correct indication of the strength the sand will develop under actual work conditions, they should be made of a corresponding consistency.

Clinker, or the ashes from boilers, and particularly from refuse-destructors, may also be used as the basis of a material for bricks. Its composition varies greatly, but its most important constituent is a calcium alumino-silicate allied to Portland cement, though by no means identical with this substance.

The value of clinker as a raw material for brickmaking depends largely on the proportion of permanent alumino-silicates in it, but as the composition of these is extremely complex, very little information can be gained from an analysis of the clinker. An analysis of a typical clinker shows the following figures :

Silica	40.6	per cent.
Lime	11.2	,,
Alumina	18.5	,,
Ferric oxide	22.8	,,
Magnesia, manganese, alkalies, etc.	6.9	,,
	100.0	,,

These figures relate to clinker from a municipal refuse-destructor, this material being specially suitable for the manufacture of bricks for the following reasons :

(*a*) It is usually very uniform in composition.

(*b*) It is usually rich in suitably complex alumino-silicates and free from objectionable impurities.

(*c*) When crushed its grains are of suitable shape and can be graded without difficulty.

Clinker from boilers is not always sufficiently uniform or of a suitable composition to enable satisfactory bricks to be made, but when these conditions are satisfied it is equally as useful as that from destructors.

In Paris, boiler-clinker is extensively used for brickmaking.

The physical properties of clinker to be used for making bricks should be similar to those for making sand (p. 8) and the material should be graded with equal care.

The fact that clinker is a waste product and is very cheap is an important factor in its use.

SLAG. The chief waste product from blast furnaces, termed *slag*, is a semi-molten material resembling a dirty glass, and (when mixed with lime) it has many properties in common with unground Portland cement. Like the latter substance, slag consists chiefly of highly complex calcium alumino-silicates, their composition varying considerably in different works, but usually remaining remarkably constant in any one works. This fact enables almost any blast-furnace slag to be used very successfully for the manufacture of bricks when once its composition and general properties are understood.

Blast-furnace slags cannot well be said to have a single typical composition, as they are made by adding such proportions of limestone to iron-ore as will enable the siliceous and aluminious matter in the ore to combine with the lime and form a mass of sufficient fluidity for it to separate readily from the molten iron. As the proportion of the silica and alumina in the ore vary greatly, so must the composition of the slag. On the other hand, the fact that the slag must have sufficient fluidity at the working temperature limits its general composition to something like the following :

Lime	25–50 per cent.
Alumina	15–20 ,,
Silica	25–40 ,,
Calcium sulphate.	0– 3 ,,
Calcium sulphide	0– 6 ,,

If the ratio $\frac{CaO}{SiO_2}$ falls to unity the slag is probably unsuitable for brickmaking If it contains much sulphur it is equally undesirable.

Some of the material reported in analyses as ferric or ferrous oxide is not infrequently in the form of metallic iron. If the proportion of this metal is sufficiently large it will pay to extract it magnetically (*see* p. 16).

The slag when it first issues from the furnace is in a molten condition and at a high temperature. It may then be granulated at once or it may be allowed to cool naturally and then carted away to a tip. The latter was the usual means of disposing of it and is the method still used by many firms. Old slag which has been tipped in this manner may be used equally as well as that which has just come from the furnace, but the costs of loading and crushing it are greater than that of granulating the fresh molten slag. Hence, where the furnaces are still in operation it is usual to employ the fresh slag rather than that which has been tipped. In cases where no fresh material is available, the old slag is equally suitable.

Old (tipped) *slag* must be crushed in the same manner as stone (p. 27) and it must then be tested as to its grading, the correct proportions of particles of the various sizes being then adjusted in the same manner as sand (p. 9).

FIG. 6. Magnetic Separator.

The metallic iron and magnetic oxide present may be recovered by passing the crushed material over a magnetic separator (Fig. 6). This consists of a horizontal drum carrying a series of powerful electro-magnets. The crushed material flows over the drum in a thin stream, so that the iron adheres to the magnets and is afterwards liberated by automatically cutting off the magnetizing current. In this way the slag is delivered to the front of the separator and the iron falls into a well or hopper at the back of the drum. The separator is quite automatic in action and the iron recovered is amply sufficient in most cases to make the installation of the separator a profitable investment.

Fresh slag may be granulated in either a wet or dry manner, several modifications of each process being in use. Immediate granulation is cheaper than receiving the slag in ladles and then taking it to the tip.

In *wet granulation*, the slag issuing from the furnace in a molten stream falls into a trough of running water and is cooled so suddenly that it falls to a coarse sand-like powder. This powder is carried along by the water into (*a*) a sump or well from which it is removed by an elevator with perforated buckets ; (*b*) perforated waggons standing over a drain, so that the water runs out and leaves the granulated slag behind. The latter method is cheaper and it is generally preferable to the former one. In either case the slag, when well drained, is ready for brickmaking. The process is cheap and effective, but with some slags it yields a spongy material which persistently retains an excessive proportion of water.

Various other modifications of the way in which the water is applied are in use.

Wet granulating has the advantage of slaking any free lime or hydraulite in the slag. It also assists in the removal of sulphur compounds, which are objectionable as they are liable to produce a scum on the bricks.

The slag coming from the blast furnaces varies in its chemical contents and the temperature at which it leaves the furnace also varies, and, depending on the temperature and its composition, it forms either a light slag containing up to 40 per cent. of water or a heavy slag with as little as 5 per cent. of water. If the slag is thrown in a heap and the material for brickmaking taken from the bottom of the heap, a sufficient mixing of the varying grades of slag is obtained, and in this way it is easy to overcome any undue moisture in the lighter slag.

Usually, in making bricks from wet granulated slag, the bricks are made up wet—so wet that at every pressing water is pressed out of the bricks. The proportion of moisture in such slag is about 20 per cent.

The use of crushing rollers for crushing granulated slag is not now considered necessary, though formerly they were employed with a view to removing any excess of water in the slag. In one plant in South Wales where such rollers were put in they are not now used. In another case where crushing rollers were installed fifteen years ago for the same purpose, they were also discontinued as being quite unnecessary.

In *dry granulation* much less water is used, and this is an important advantage over some slags. The slag, as it issues in a molten state, falls into a revolving drum up which a powerful stream of air and water is blown, and this disintegrates the slag as before. The chilled particles fall against the sides of the drum, and as the latter is cooled externally with water and is provided internally with baffles, the slag which passes out at the lower end of the drum is sufficiently fine and cool to be transported without difficulty. This method of granulation is easier to manage than the wet process and it yields a relatively dry slag, but it is more costly on account of the power required to produce the air-blast and to drive the drum.

Metallic iron, if present, may be removed by a magnetic separator as described on p. 16.

Crushed rock. This must be made from a comparatively pure quartz or quartzite, the composition and properties of which, when crushed, do not differ materially from that of the sands from which the best lime-sand bricks are made (p. 4). The cost of crushing rock is usually so great as to make the use of this material too expensive, except in special circumstances. In some localities, the use of *quarry waste* in this manner is remunerative.

Broken Bricks may be used as an aggregate where there is a sufficient supply to make the erection of a plant remunerative. For use, they are ground to a sand-like powder.

Burnt Shale—which is found at many collieries—is an excellent material for making bricks, and where there is trouble with clay containing limestone one of the best ways of utilizing it would be to burn it into *ballast*, and then to make it into bricks by the lime-sand process.

Bricks made from broken bricks and from burnt shale or burnt ballast can be hardened out in the open air or with low-pressure steam—like slag-bricks—or they may be hardened really well in a hardening chamber at a high pressure.

BINDING AGENTS

The binding or cementing agent in non-plastic bricks appears to be a hydrous calcium silicate, the composition of which is not definitely known. It is produced either by the action of lime on the sand or other aggregate or by the action of water on Portland cement when the latter is added to the aggregate.

Various other binding agents, such as water-glass—a soluble sodium silicate—or the basic chloride made by treating lime with hydrochloric acid (Kleber's patent, 1897), have also been used, but lime still constitutes the most important of all the bonds, and it and Portland cement are the only two bonds now in extensive use.

Lime. This will be purchased as it is required in such quantities that it would not usually pay to burn lime specially for brickmaking—at any rate in Great Britain. In newly settled districts, where a sale for lime can be cultivated, the burning of lime forms a convenient auxiliary business to that of making bricks.

The best lime for the purpose is a rich or fat lime, consisting almost entirely of calcium oxide. Dolomitic lime (which contains magnesia in notable quantities) is far from satisfactory, because it is so slowly hydrated that even with steam it is sometimes improperly slaked. This is partly due to the fact that in order to burn the lime properly the magnesia in it is overburned. It is quite possible to produce excellent lime-sand bricks from a dolomitic lime, but it must be treated in a more thorough manner to secure its complete hydration, and so is more costly to handle than a pure calcium lime. Theoretically, magnesia might be expected to work more powerfully than true lime, but in actual practice it is found not to do so as it gives out less heat during the slaking.

If the slaking of the lime is incomplete, the bricks will "blow," and may even crack in the hardening chamber. Hence, the necessity of obtaining a lime which slakes readily and which has not been overburned.

Another objection to dolomitic or magnesian lime is the large quantity required. As the ordinary methods of making lime-sand bricks only use the calcium oxide in the lime—the magnesia being so feeble in its action as to be almost useless—it is clear that a dolomitic lime containing 60 per cent. of calcium oxide and 40 per cent. of magnesia will be worth less than two-thirds as much as a pure calcium lime. Hence, apart from the trouble involved in using a dolomitic lime, it seldom proves to be as cheap as a high calcium lime if its value is based on its binding power.

As a rule, limestones which have not been heated to about 1100° C. produce the best and most readily slaked limes and those with the greatest binding power, yet test observations with a pyrometer have shown that many lime-burners reach temperatures over 1400° C. in their kilns, with the result that some over-burned lime is always present, and it is this portion which causes trouble to the lime-sand brickmaker.

Even the best lime is seldom perfectly uniform in composition; some under-burned as well as some over-burned pieces are almost invariably present, and both these are equally useless, though, of the two, the under-burned pieces are the least harmful in the manufacture of bricks. This irregularity in composition and properties is the cause of several difficulties in brickmaking—all of which may, however, be overcome if the nature of the raw material is properly recognized.

It is of the greatest importance that a hydraulic lime, such as Blue Lias lime, should not be used except under specially skilled advice, as hydraulic lime does not develop the necessary amount of heat and forms quite a different compound with the aggregate to that produced when a pure calcium lime is used. This must not be understood to mean that under no circumstances can hydraulic lime be used, but that it requires such modifications in the procedure that it is better not to use it. If a hydraulic lime is substituted for a rich calcium lime and the ordinary method of brickmaking is continued, the bricks will fall to pieces in the hardening chamber.

The pure lime (calcium oxide) when mixed with water combines with it, evolving a considerable quantity of heat (210 calories), and increases greatly in volume. The amount of water which enters into combination is 32 per cent. of the calcium oxide present, but, in slaking, much more than this must be added as so much passes away in the form of steam.

The impurities in the lime (iron oxide, silica, alumina, etc.) behave quite differently and reduce the amount of heat evolved and the swelling. If one of the impurities in the original limestone is clay it would produce a hydraulic lime, which has already been stated to be undesirable. If the proportion of impurity is such that only about 65 per cent. of lime is present, a cement may be formed which has valuable properties in itself but is useless for lime-sand bricks as it will not slake at all!

Even small percentages of impurities in the lime are serious, as so little lime is used relative to the proportion of sand. It is, therefore, important that the lime should be pure. It is not difficult to obtain lime containing less than 3 per cent. of impurities, and this should be used whenever possible, as it costs so little more than the inferior qualities and more than repays for itself in the smaller quantity required and in the better quality of the bricks.

The lime purchased should always be tested, as if underburned it will not contain sufficient quicklime, and if overburned it will not slake properly.

It is important that the sample taken for testing is truly representative of the bulk. This can only be ensured by picking at random as many lumps of lime as will weigh about half a ton, breaking these sufficiently small to pass through a hole 2 in. in diameter and then mixing this broken material well with a spade. The heap is cut with the spade into four parts or quadrants, and two opposite quadrants are then removed. The residue is broken to the size of walnuts, and is again mixed and divided into quadrants. This process of crushing, mixing, and dividing is continued until about six pounds of material is obtained. This is taken to the testing-room, reduced to a coarse powder, and the quartering continued until about one ounce is obtained. The tests are made on this material, which is as truly representative of the bulk as any sample can be.

It is hopeless to pick up two or three lumps at random and to judge the quality of a waggon-load from these, as the composition of lime is too irregular for such a test to be accurate. The slower method of quartering is the only one which is even roughly accurate.

There are several methods of testing, but some of the best for the brickmaker consist (*a*) in weighing out 2·800 grammes of the powdered sample as accurately as possible, placing it in a glass beaker, mixing it slowly with a gill of distilled water and, when it is slaked, boiling it. Ordinary water must not be used as it may contain other lime compounds. After boiling for several minutes the liquid is allowed to cool; a few drops of phenolphthalein solution are then added, and "normal hydrochloric acid" run in, drop by drop, from a burette in such a manner that the volume of this acid used can be accurately known. The colour of the phenolphthalein will be discharged on the addition of acid, but on stirring it will be restored. When about 60 c.c. of acid have been added a teaspoonful of sal ammoniac is added, the solution is stirred until it is dissolved, and the addition of acid is continued in small quantities at a time until the colour of the solution is permanently discharged. The addition of acid is then stopped and the volume used is noted; it is necessary that the lime solution should be stirred all the time the acid is being added and that too much acid should be avoided. It is better to make several tests from different portions of the batch of lime, and these should all give the same result within $\frac{1}{5}$ c.c. As 1 c.c. of the "normal acid" equalls exactly 1 per cent. of lime, no calculation is necessary. One caution may not be out of place, however, viz., the acid used must be truly "normal" and be specially prepared for this kind of work, so that it contains exactly 36·5 grammes of hydrochloric acid gas per litre. The ordinary commercial acid is quite useless, but the "normal" or "standard" acid can be obtained from most manufacturing chemists for about 2*s.* 6*d.* per pint, or it may be made by following the directions given in any good work on volumetric analysis.*

If the amount of acid used in the above test falls below 98 c.c. some inquiry should be made as to the cause. It may be that the lime is underburned, in which case the liquid may be filtered; the residue on the filter-paper will then "fizz" if acid is poured on to it, or an impure stone may have been supplied or—what should never be overlooked—some error may have been made in the test.

If magnesia is present to a noticeable extent in the lime thus treated it will have the effect of lowering the amount of acid used, though small quantities will not be detected this way. For most purposes, however, the magnesia thus over-

* *See* Appendix.

looked is unimportant, though larger quantities of it must be avoided, as they are useless to the lime-sand brickmaker.

The detection and estimation of the magnesia is a troublesome piece of work and should be left to skilled chemists, who will do it far more accurately than a man without the necessary appliances. For most purposes, a few analyses by a chemist when the lime is bought, followed by a daily test of the lime used, as described above, will give sufficient control, as the same firm seldom, if ever, manufacture pure lime and dolomitic lime.

In any case, the lime should always be bought according to the proportion of pure lime (calcium oxide) it contains, though it is not always necessary to disclose this to the dealer, as some firms do not know the value of the lime they sell.

(*b*) Another rough guide as to the value of a lime for brickmaking may be obtained by carefully stirring up a weighed amount of lime with an accurately measured quantity of water, and noticing the highest rise of temperature obtained. This test is best made in a thin glass "beaker," obtainable from any dealer in chemical apparatus, which should be placed inside a large jar, the space between the two and below the beaker being packed with cotton-wool to prevent loss of heat. The stirring should be done with a "chemical thermometer" and the temperature should be noticed every few seconds. This rough test will readily enable good limes to be distinguished from poor ones, though it will not always distinguish between two good limes of about the same value. The amount of the increase of temperature will depend on the composition of the lime, as well as on the amount of air-slaking which has taken place. The maximum temperature which can be obtained decreases with the increase of the percentage of magnesia as well as with the increase in the amount of air-slaked lime present; therefore, it would be necessary to establish constants which represented the maximum heat generated for the lime in use at any particular plant. The time required to reach the maximum temperatures under standard conditions would be a guide to the burning conditions. If overburned, the slaking will be slower and more time will be required to reach a maximum temperature.

(*c*) Another good test of the value of the lime is to make it into lime-sand bricks and to ascertain the force required to crush these. The bricks which are strongest are obviously made of the best lime. Several bricks should be tested, as the variations in results may be too great if a single brick is made.

Occasionally a sample of lime should be sent to a testing laboratory * so that the specific gravity, loss on ignition at 1000° C., and the total impurities may be determined and used as guides in the selection of the lime and in the control of shipments.

There is no doubt that if brickmakers would spend considerable time, money, and energy on this matter in order to establish a few standard requirements, and at the same time use some simple tests, such as those described, at each plant, so as

* That of the author is available for this purpose.

to test each lot of lime received, they would find their money well spent. Not only would they be certain of what they are getting, but the tests have an important indirect value. For instance, if a lime manufacturer has a few lots condemned and thrown back on his hands, and knows his customers are testing his product before use, he will be more careful what he sends to them.

The character of the lime used is of the greatest importance to the maker of lime-sand bricks, and any means which he can use to secure a superior quality of lime are all in his favour. In any case, the proportion of lime is always so small that a few pence extra per ton are as nothing if better bricks can be obtained. Hence, when once a suitable source of lime has been found, it should not be changed except for unusually good reasons, as a faulty lime is one of the commonest causes of failure.

Almost any reasonably clean sand will, with a good and properly prepared lime, make a good brick, but no matter how good the sand, if the lime is not right it cannot give a satisfactory brick, so that it is very important to the brick-manufacturer not merely to procure a lime which has the most desirable chemical composition and has been burned under such conditions as to make it the most sensitive in slaking, but to purchase it in frequent and small shipments, as a very sensitive lime will be more susceptible to air-slaking during transportation and storage. This does no damage to the bricks as a whole, but it reduces the efficiency of the lime in the hardening cylinder and necessitates the use of more lime than would otherwise be needed.

At the present time, anything is considered lime that will make an appearance of slaking and give some sort of a bond in mortar. The time will come, however, when there will be established standard tests and requirements on which purchases of lime will be made, just as is the case for many of the raw materials for use in cement and other industries. Meanwhile, each brick-manufacturer should make his own tests as described on p. 13, and should either burn his own lime or else contract for it under definite specifications as to its condition and composition on its arrival at the plant, because, when the lime is just right, 7 per cent. will often do the work of 10 per cent. of an imperfectly burned lime or one that has been badly air-slaked or overburned.

The lime-sand brick-manufacturer should therefore purchase a lime that has less than 2·5 per cent. of total impurities. He should also use a lime which contains more than 94 per cent. of calcium oxide, and the nearer to 100 per cent. of calcium oxide it is the better will it be. He should also have a lime that has been very recently burned, but it should be one day old before slaking, since hot lime straight from the kiln does not slake so freely and completely as lime that has cooled for twelve hours or more.

There was, at one time, a large amount of discussion as to whether the lime should be used in the quick or slaked condition.

Olschewsky and his agents maintained that the use of slaked or hydrated lime was essential, but more recent experiments have shown that it is advantageous to mix quicklime with the sand or other aggregate, and to take advantage of the heat evolved on adding water to the mixture, instead of wasting this heat as is the case when the lime is slaked separately. It is, moreover, extremely difficult to slake the lime uniformly without making too wet, whereas when it is mixed with sand and then slaked, the reaction is more uniform and the risk of particles of unslaked lime can be reduced to a minimum. A further drawback to hydrating the pure lime is the cost of handling it; various arrangements of boxes in the autoclave were tried, but the only satisfactory method is to use a hydrating drum and to screen out the unslaked material. When quicklime is employed without pre-hydration, some unslaked particles may become incorporated with the bricks, but apart from this, the use of quicklime offers no real difficulties; it obviates unnecessary handling, simplifies the manufacture and very often gives a better product.

Instead of hydrating the lime before use, it is increasingly the practice to grind it in a ball-mill to so fine a powder that it will pass completely through a sieve having thirty to fifty holes per linear inch. The plant for the purpose is described in the next chapter.

The *amount of lime required* varies according to its purity and slaking power, about 6 per cent. being needed in the most advantageous conditions; 7 to 8 per cent. is quite usual, though as little as 3 per cent. may sometimes be used. If each brick weighs seven pounds, these figures show that for an output of 20,000 bricks per day between four and five tons of pure high calcium lime will be required daily, but if the lime contains only 70 per cent. of calcium oxide (for example, dolomitic lime) between six and eight tons will be needed. De la Roche has concluded from experiments made by himself that the proportion of lime used depends on the pressure applied to the bricks! These experiments certainly showed that a larger percentage of lime is needed with a low pressure in the press to produce bricks of a definite crushing strength than when a high pressure is used in forming the bricks. Thus, to produce bricks of a minimum crushing strength permissible in Germany (*i.e.* 2000 lb. per square inch), a certain sand required 15 per cent. of lime, with a press-pressure of 3600 lb. per square inch, but only 8 per cent. of the same lime when the pressure in the machine was doubled. This result is probably due to the particles being pressed closer together so that the mass has a smaller proportion of voids when a higher pressure is used. More recent experiments by the author have shown that if the material is properly graded, the amount of lime required is largely independent of variations in the pressure. Correct grading is both better and cheaper than the employment of excessive pressures, and should be regarded as essential to the manufacture of the best qualities of non-plastic bricks.

As already explained, the ideal aggregate is one in which the voids are occupied as fully as possible by fine grains of sand or similar material, the lime being in the form of a coating around each grain. When the material has been graded to secure this condition, the amount of lime required will be quite small—in some cases as low as 3 per cent.—and no difficulty should be experienced in using 5 to 6 per cent.

of lime. If for some reason the grading is imperfect, a larger proportion of lime will be required, but if more than 10 per cent. is needed there is something wrong.

In stating these proportions it is assumed that a good fat lime is used; if a slowly slaking, impure, or badly burned lime is employed, a proportionately larger percentage will be required and there is a great probability that the bricks will be of inferior quality. It is not so much the proportion of lime present as its quality and the completeness of its distribution which determine the amount required.

Storage of Lime. When lime has to be stored before use it should not be kept in an open shed but in a properly built lime-vault. When lime is stored in rooms which are really no better than open sheds, the air coming in around the doors and windows, and often through the walls and floors, will surely slake it, and this is descriptive of the usual storage-place for lime. It is not difficult, however, to keep bulk lime from slaking if the proper precautions are taken. The accompanying sketch (Fig. 7) will explain all that is required. The vault proper is really one box inside another, the space of 6 in. between them being filled with slaked lime or other suitable material.

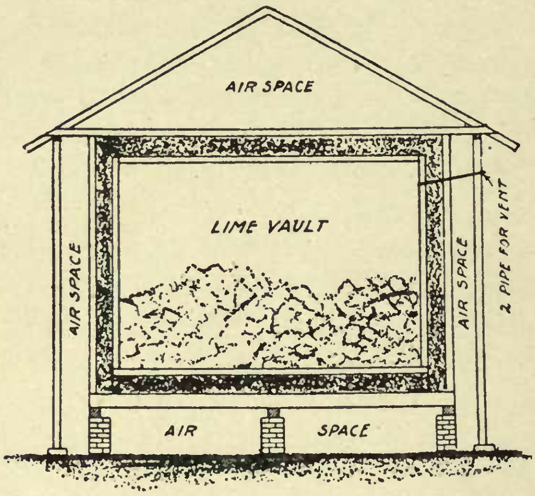


FIG. 7. Lime Store

Around the box or vault is built the house, leaving an air space of 6 in. between the vault and the walls of the building. On the top of the building is a ventilator, the object of which is to create a current of air around the vault; to secure this current, air must be admitted at the bottom.

In some houses, a pipe 1½ or 2 in. in diameter—represented by a black line on the diagram—extends from the vault through the walls, its object being to let off gases. It should be so constructed that it will close automatically.

The door should be made with care. Carpenters often exercise all the skill they possess in building the walls as tightly as possible and then put in doors around which the air can enter as though they were sieves. The smaller the door the smaller the volume of air which will come in contact with the lime when it is opened. A door 3 ft. × 3 ft. is large enough, as through a door of this size with a long-handled shovel every part of the vault can be reached. For durability, the floor should be of hard wood—either birch or maple is excellent—the friction caused by lime and shovel quickly wearing through soft wood. There must be provision for shovelling the lime into the house, and to meet this requirement a small door must admit into the vault near the top. This door should also be air-tight when shut.

The plan described is the one involved in the building of all lime-houses which have proved satisfactory, though it may be modified to make the vault in the shape of a hopper. In this case it is better to have the boards set on a slant and made of hard wood, so that the lime will not wear them rough and then cling to them.

PORTLAND CEMENT. As previously remarked, Portland cement may be used as the binding agent for non-plastic bricks. This substance is usually sold in accordance with a standard specification, and, providing it conforms to this, there need be no anxiety as to its value. It is, however, important to specify whether quick-setting or slow-setting cement is required, the latter being usually the best in brick-making.

WATER. In order to effect the necessary reaction between the aggregate and bond, it is usually necessary to add a suitable quantity of water. This should be as clean and soft as possible, as dirty water reduces the strength of the bricks, and hard or salt water tends to form a scum on the surface of the goods.

The amount of water required must be found by trial, as it depends on the wetness of the sand or aggregate. In some cases the latter must be partially dried before use, but this should be avoided as far as possible as it is very costly. It will usually be found that, providing the lime is slaked and a uniform mixture is secured, the less the proportion of water present the stronger will be the bricks.

OTHER MATERIALS. With a view to obtaining patents or other financial advantages, a number of people have advised the use of various materials in small quantities. The use of such additions is almost invariably detrimental, and as they increase the cost of manufacture without any adequate advantage they should be avoided.

CHAPTER III

PREPARING THE MATERIALS

In the manufacture of lime-sand, clinker or slag bricks, a mixture is used which consists approximately of

Aggregate (sand, clinker, or slag) . .	85	per cent.
Lime	8	,,
Water	7	,,
	100	,,

In order to produce satisfactory bricks it is necessary :

(*a*) That the aggregate should consist of particles of the correct sizes. (To effect this it may be necessary to grind some or all of the material to suitable degrees of fineness, p. 11.)

(*b*) That the proportions of particles of various sizes should be such as to produce a mass with a minimum of voids. (This may be effected by grading as described on p. 9.)

(*c*) That each grain of aggregate should be coated with lime. (This is effected by efficient mixing.)

(*d*) That the lime should be distributed as uniformly as possible.

(*e*) That the lime should be properly and completely hydrated before the material is sent to the presses. (*See* Chap. V.)

Unless these requirements can be satisfied it is impossible to make good bricks. For instance, if any lime is present in the bricks in an unslaked condition it will cause the bricks to swell or crack during the heating in the autoclave.

To secure the foregoing conditions the three essential ingredients—aggregate, lime, and water—must be:

(1) Ground to the requisite fineness and graded (if necessary).

(2) The proper proportion of each must be weighed or measured.

(3) Mixed to form a homogeneous mass in which the lime is fully hydrated.

Drying the Aggregate. It is seldom necessary to dry the aggragate by artificial heat, and indeed, this should be avoided whenever possible on account of its cost. If the sand does not contain more than 8 per cent. of water it may be used without any treatment and the addition of any further water is then unnecessary. Schwarz has stated that it is necessary to have a definite proportion of water in the sand ;

this is true within certain broad limits, but it is seldom necessary to dry the sand artificially in order to secure this. The ordinary variations in the proportions of water in the aggregate do not affect the quality of the bricks. If more than 8 per cent. of water is present, the sand may be drained by laying it on a sloping, impervious bed of concrete or wood, and exposing it to the air for a few days. If this treatment is insufficient the sand will have to be dried by heat, but it is then so questionable

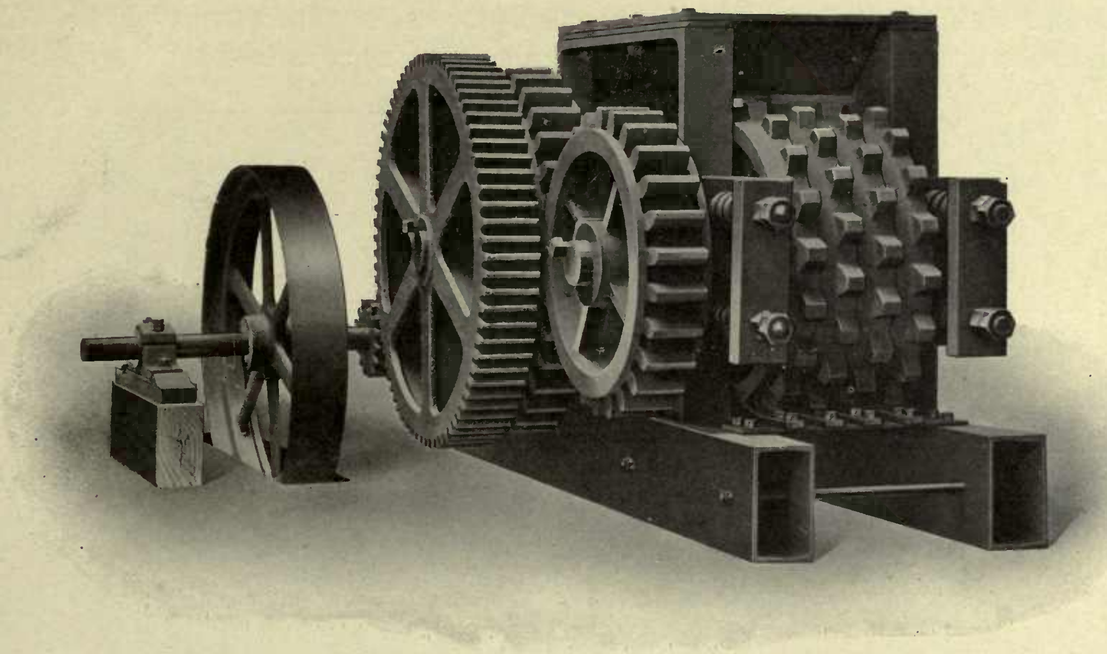


FIG. 8. Crushing Rolls

Courtesy of Sutcliffe, Speakman & Co. Ltd.

whether it will pay to use it that an independent and impartial expert on lime-sand brick manufacture should be consulted before a drying plant is installed.

Grinding the Aggregate. Generally speaking, sand and granulated slag will not require to be ground, though it is highly advantageous to grind a portion to an almost impalpable powder in order to fill up the smaller voids and to convert it into a state in which it will combine more readily with the lime. Rock and clinker and ungranulated slag, on the contrary, require to be reduced to a coarse, sandy powder. According to their hardness they may first be crushed to pieces of ½ in. diameter in crushing-rolls (Fig. 8) or in a jaw-crusher or disintegrator, or they may be fed directly to an edge-runner mill with revolving perforated pan, fitted with heavy runners (Figs. 4 and 9). It is essential that this mill should be of ample strength and the runners of sufficient weight, or the material will not be crushed in an economical manner. There is a tendency on the part of users to select too light a machine ; this, though cheaper in first cost, is far from economical, and it is far better to have a mill which is too heavy rather than one which is too light. The perforations in the pan may conveniently be $\frac{1}{8}$ in. in diameter.

It is exceedingly important that the material should be fed in as uniform a manner as possible, as otherwise the output of the mill will be reduced.

The product from the mill may require to be screened in order to separate it into various sizes or grades, so that these may be re-mixed later in suitable proportions. In many instances this is unnecessary, as the rubbing action of the mill produces grains of all sizes, and these not infrequently occur in suitable proportions. The best method of determining whether screening is necessary is to carefully grade the

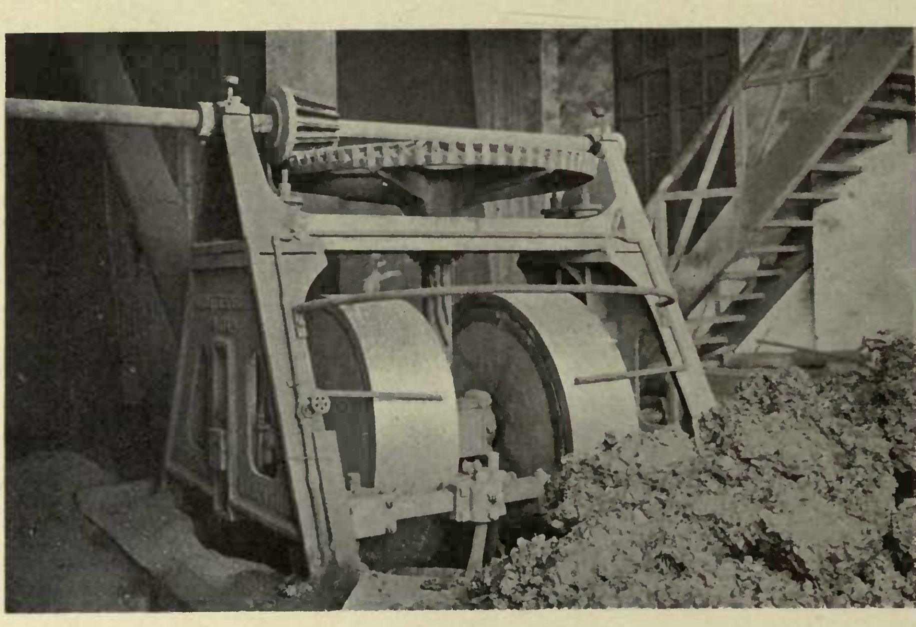


FIG. 9. Clinker Grinding Mill at Havre

Courtesy of Sutcliffe, Speakman & Co. Ltd.

material by hand as described on p. 9, and then to mix the different grades in various proportions so as to obtain a material with the minimum of voids (*see* pp. 8 to 10). On making these various mixtures into bricks and testing the latter, the amount of screening and grading needed will soon be ascertained.

Unless the material is very damp, quite a simple screen, such as that described on p. 31, will suffice.

Materials of a sandy nature cannot be screened effectively if they are so damp that the particles adhere to each other like those in sand on the sea-shore. In such a case, the material must be dried before grinding it. Sometimes a damp material may be dried sufficiently by adding the lime to it in the grinding-mill. The lime is slaked by that portion of the water with which it combines and a further quantity of water is evaporated by the heat produced on slaking the lime.

Testing the Aggregate. The ground and, if necessary, screened aggregate is then ready for use. It should be tested daily by determining the proportion of voids (p. 10), and if these indicate that it has not been properly graded it should be still further tested by passing through a series of standard testing-sieves. The information thus obtained will show whether a further separation of the bulk of

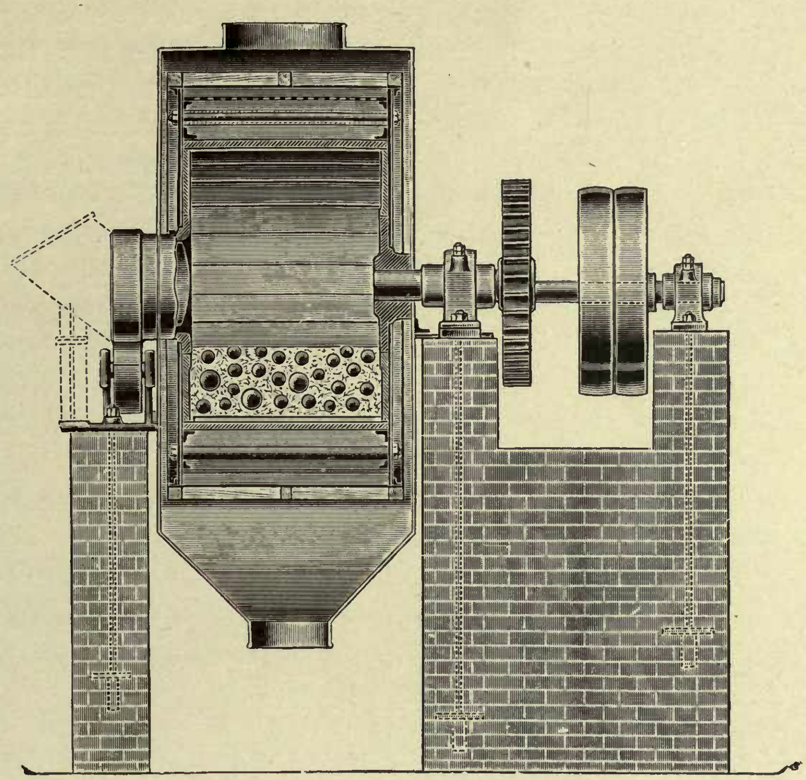


FIG. 10. Section of Ball Mill

Courtesy of Sutcliffe, Speakman & Co. Ltd.

the material into several sizes of grains is necessary; if so, this must be done with a special series of screens.

In testing the aggregate, allowances must be made for the effect caused by the addition of finely ground sand or flour-sand (if this is used).

GRINDING THE LIME. Quicklime of good quality is ground (*a*) alone in a ball-mill to such a fineness that it will pass completely through a sieve with thirty to fifty holes per linear inch, or (*b*) it may be mixed with twice or three times its weight of aggregate and ground in a tube-mill to the fineness of Portland cement, viz., so that it will not leave more than 20 per cent. of residue on a sieve with 200 holes per linear inch. With sand the former method is less satisfactory than the latter, but for clinkers and slags it may often be used with success. There is so much advantage to be gained by grinding the lime and some aggregate together to an extremely fine powder, that this method is far preferable to the other.

This may easily be seen by examining, under the microscope, pieces of bricks made from the materials treated by both these methods.

It is usually desirable, for the sake of economy in working, to reduce the lump lime to small pieces in a hammer-mill or disintegrator. To keep down the amount of dust, the disintegrator should not be arranged to grind the lime to powder, but only to crush it into small pieces. The further grinding may then be done in a ball- or tube-mill of suitable design.

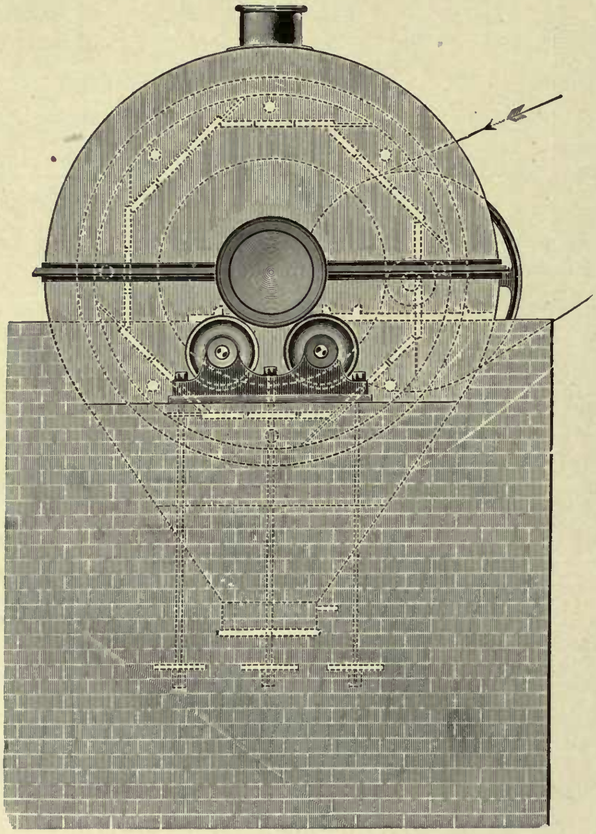


FIG. 11. End View of Fig. 10

When a crusher is used, it is important not to leave the crushed lime about for more than a very short time, as it easily carbonates and spoils. The best way is to crush just as much as will be needed for the day's work if the ball-mill holds a day's supply at a charge, or for a single charge of the mill if a smaller mill is used. A little attention will enable a regular plan to be evolved, whereby all danger of the crushed lime being spoiled by exposure may be avoided.

If preferred, crushing-rolls (Fig. 8) may be used, but they are more provocative of dust, and the wear-and-tear is greater.

The *ball-mill* used for grinding the lime alone may be any suitable pattern. Its general construction is shown in Figs. 10, 11, and 12, from which it will be seen that it consists of a steel cylinder lined with plates of specially hardened metal and supplied with a number of steel balls about 2 to 4 in. in diameter. The lime to be ground is fed continuously into the mill and, as the cylinder revolves, the balls fall on the lime and crush it to powder, and the powdered lime is discharged automatically and continuously through a sieve into a suitable hopper.

The disadvantage of the ball-mills lies in the ease with which the sieve becomes clogged, and the wear-and-tear on the sieve is also somewhat heavy. It is, for this reason, very difficult to use a sieve finer than No. 15 to No. 20 where a large output is desired.

A sieveless ball-mill is shown in Fig. 12; it is similar to a tube-mill but shorter, and avoids all the drawbacks attending the use of sieves.

An important attachment in connection with the fine grading of the lime and sand consists in the use of an air-separator in place of a sieve or riddle. This arrangement, originally devised by R. Moodie, but greatly improved by Gebr. Pfeiffer (Figs. 13, 14, and 15), consists of a horizontal plate rotated at a considerable speed within a casing of special shape. The material from the mill is fed on to this plate by means of an elevator; the fine particles are thrown off by a centifrugal action to a considerable distance, while the coarser particles fall short. In this way a separation of the material is effected without the disadvantages inevitably connected with sieves. Several old patterns of air-separator now on the market are unsuitable for

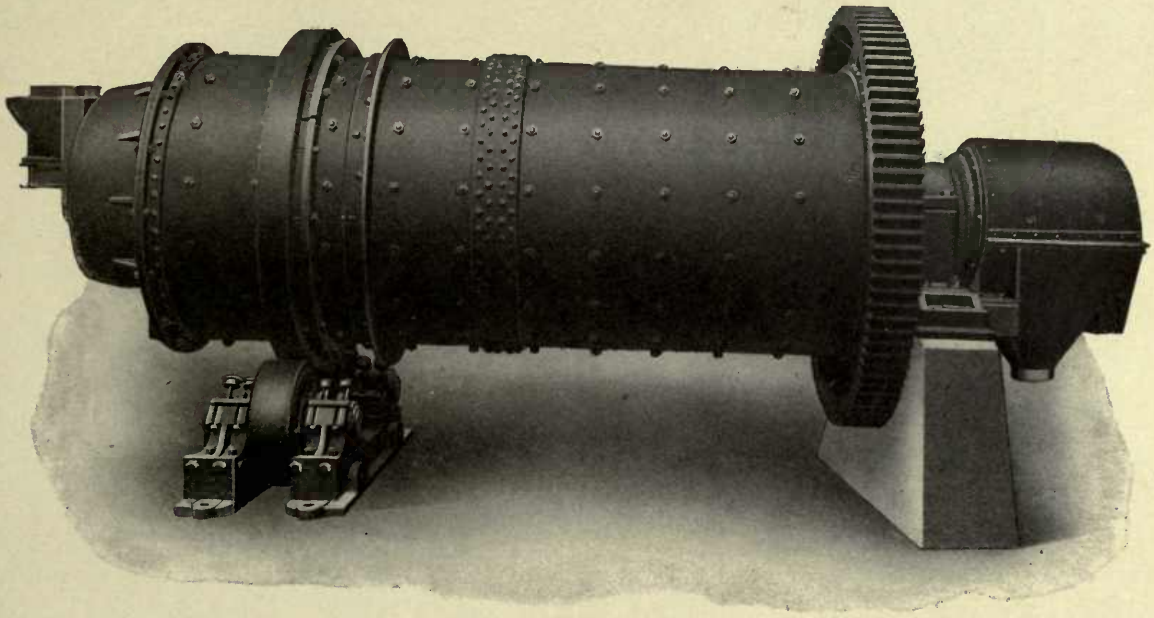


FIG. 12. Ball Mill
Courtesy of Sutcliffe, Speakman & Co. Ltd.

grinding lime and sand, but the present writer has found the more recent designs of Gebr. Pfeiffer to be quite satisfactory with lime-sand mixtures containing not more than 50 per cent. of lime.

The action of the air-separator is readily seen in Figs. 14 and 15, in which the arrows indicate the direction in which the air-currents move. This is a special feature of the Pfeiffer machine, and secures the maximum separative effect with the minimum of power.

If a sieve is preferred to an air-separator, an inclined sheet of steel with perforations $\frac{1}{8}$ in. diameter will be found to give a much larger output than the ordinary rotating screen.

The advantage of an air-separator is that it enables the ball-mill to work continuously and ensures the complete absence of all large particles from the product without the troubles and drawbacks unavoidable where sieves are used. Its disadvantage is that it uses a large volume of air, and this tends to carbonate some of the lime, and thus make it useless.

The *tube-mill* used for reducing a mixture of aggregate and lime to a fine flour consists of a steel tube (Fig. 16) 10 ft. to 25 ft. in length and 4 ft. to 6 ft. in diameter. It is lined with silica-stone $2\frac{1}{2}$ in. to 4 in. thick and revolves on ties and rollers, and must

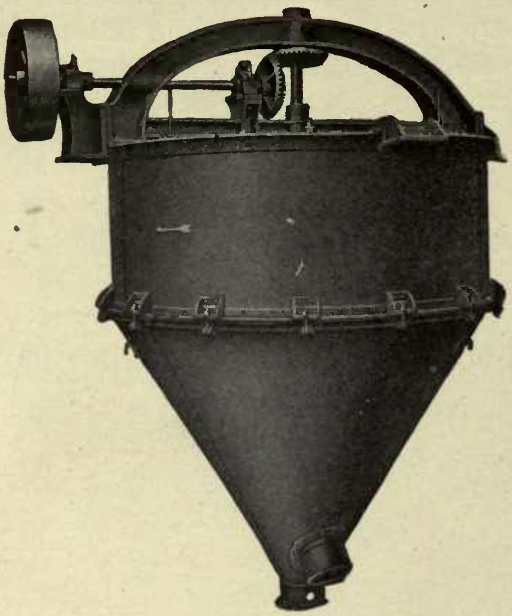


Fig. 13. Air Separator
Courtesy of Gebr. Pfeiffer

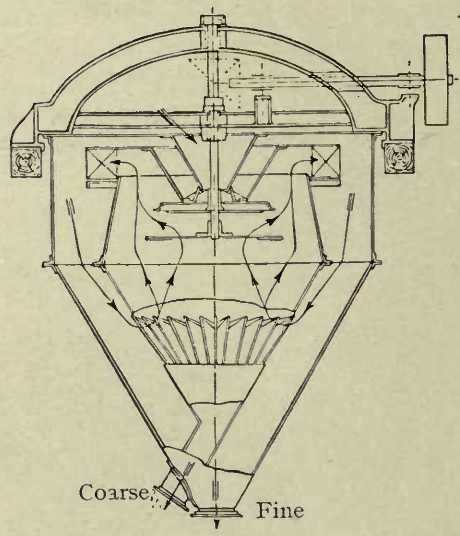


Fig. 14. Section of Air Separator
Courtesy of Gebr. Pfeiffer

be so constructed that it rotates truly. The tyres and runners should be of the best steel, of hard and durable quality, and they should be turned up true to size. The

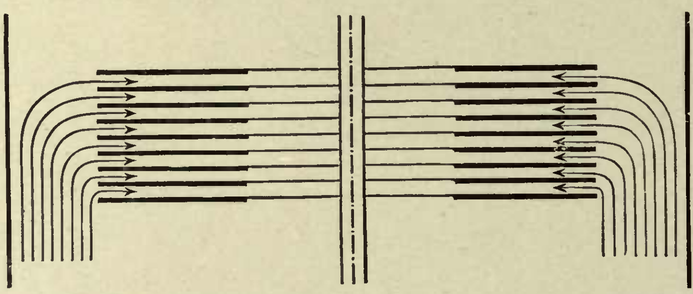


Fig. 15. Separating Plates in Selector Air Separator
Courtesy of Gebr. Pfeiffer

bearings must be well designed, properly lined with gun-metal or anti-friction metal, and accurately made.

The tube-mill is filled to rather more than half its total capacity with flint pebbles ; these should be selected both for quality and sizes, it being usually found that stones of various sizes are preferable to having them all the same diameter. New pebbles are added as required. The material enters at one end, is ground finer and finer in its passage through the mill, and is finally discharged through a suitable grating at the opposite end. To obtain the best results, a preliminary crusher is desirable, as a tube-mill is essentially a fine-grinding machine and should not be supplied with particles more than ⅛ in. in diameter.

The material to be ground is fed in at one end of the tube and eventually passes out at the other, the grinding being effected by the rolling and tumbling of the pebbles or steel balls in the mill. The grinding power of this kind of mill is so great that the hardest material can be reduced to the finest powder.

The output of a tube-mill depends on the fineness of the material to be ground as well as on its hardness. A 20 ft. tube, 4 ft. 6 in. in diameter, will require about

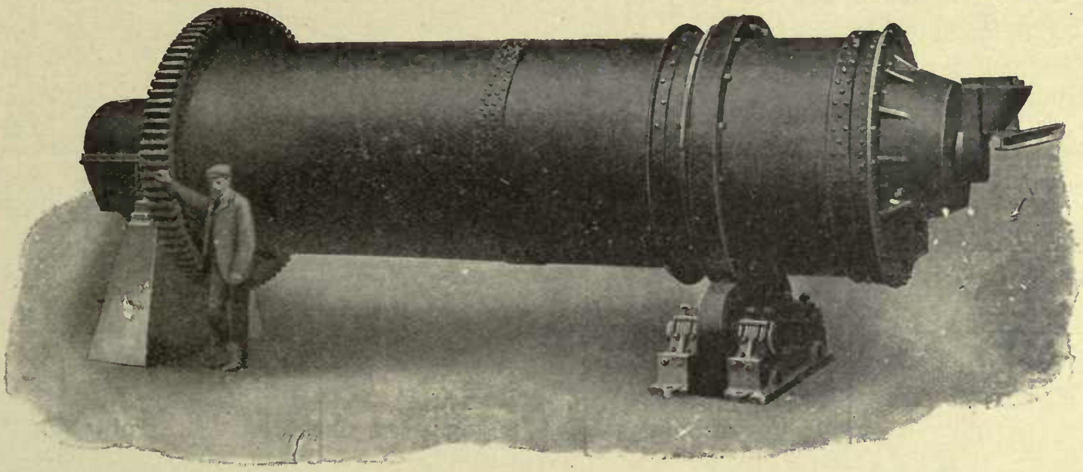


FIG. 16. Tube Mill
Courtesy of Sutcliffe, Speakman & Co. Ltd.

55 h.p. to drive it, and will produce four to seven tons per hour of ground lime and sand of the fineness of cement.

Wet Grinding. It is customary to grind the lime and part of the aggregate in a dry state, but there is evidence to show that a better result is obtained by grinding the lime, water, and the whole of the aggregate for a few minutes in a pan-mill. Such a mill consists of a revolving pan 9 ft. in diameter provided with edge-runners and closely resembles a mortar-mill in general construction. Its purpose is not so much to grind the materials as to rub them together and to secure an adherent coating of lime on each of the sand-grains. Hence, "wet grinding" has a better effect if it follows such grinding of the materials as may be necessary and, at the same time, forms the first stage of the mixing process.

It is, indeed, a mixing and not a true grinding process, and the weight of the rollers must not be sufficient to crush the grains unduly, but it must be ample to provide the necessary rubbing action, without which it is difficult to coat the grains properly with lime. If any appreciable amount of grinding does occur, allowance must be made for it when grading the material. In the United States, some amount of grinding is purposely effected in the wet pan, but in Europe this machine is used exclusively for mulling and mixing, and this latter is, in the author's opinion, its sole legitimate purpose if an accurately graded mixture is to be produced.

Some firms use a circular-pan in which ploughs or scrapers rotate and stir up the mixture, but these are not nearly so effective as a pan-mill with edge-runners, though useful as preliminary mixers. The pressure of the rollers produces a milling action which is necessarily absent when scrapers alone are used. According to Cushman, the effect of wet grinding on all siliceous rocks is to form a colloidal or gelatinous film on the surface and thus makes them combine more readily with lime than when the latter is merely stirred with the ground rock. In some of Cushman's micrographs this film is clearly visible.

The cementing value of sand when treated in a wet pan was found by Cushman to be increased by the following amounts :

Sand	Cementing power		Rates of Improvement
	Dry Ground	Wet Pan	
A	25	78	3·1
B	61	174	2·8
C	12	34	2·9

Measuring the Materials. It is essential that the various materials should be mixed in the correct proportions, and to ensure this it is necessary to measure or weigh them. Various kinds of waggons, hoppers or boxes are employed, it being sufficiently accurate to measure the sand in these. The ground lime or lime and sand may be measured in a similar manner, but the most convenient method is to use an automatic measuring machine.

A simple, but very effective form of measurer is made by having two automatic feeders (Fig. 17), one for lime and the other for sand, with an adjusting door at the base of each.

The arrangement shown in Fig. 18 consists of two or more revolving drums in which are adjustable pockets which are alternately filled and discharged. The speed of each drum can be varied as desired so that any required proportion may be readily obtained. Each pocket is scraped out at each revolution so that there is no accumulation or irregularity of discharge.

The drums discharge into a mixing trough.

The measuring machine shown in Fig. 19 also consists of a drum with two sets of pockets on its inner periphery. One set of pockets is for the lime and the other for the sand. These pockets are of such sizes that each holds the lime and sand in suitable proportions for the mixture ; these proportions can be altered as desired.

As each pair of pockets is filled their contents are completely removed by a flexible scraper. The measured lime and sand then fall onto mixing blades and are thoroughly mixed together before leaving the machine.

The arrangements shown in Figs. 18 and 19 work accurately for small outputs, but for large ones it is better to use the feeder shown in Fig. 17 or to have the lime

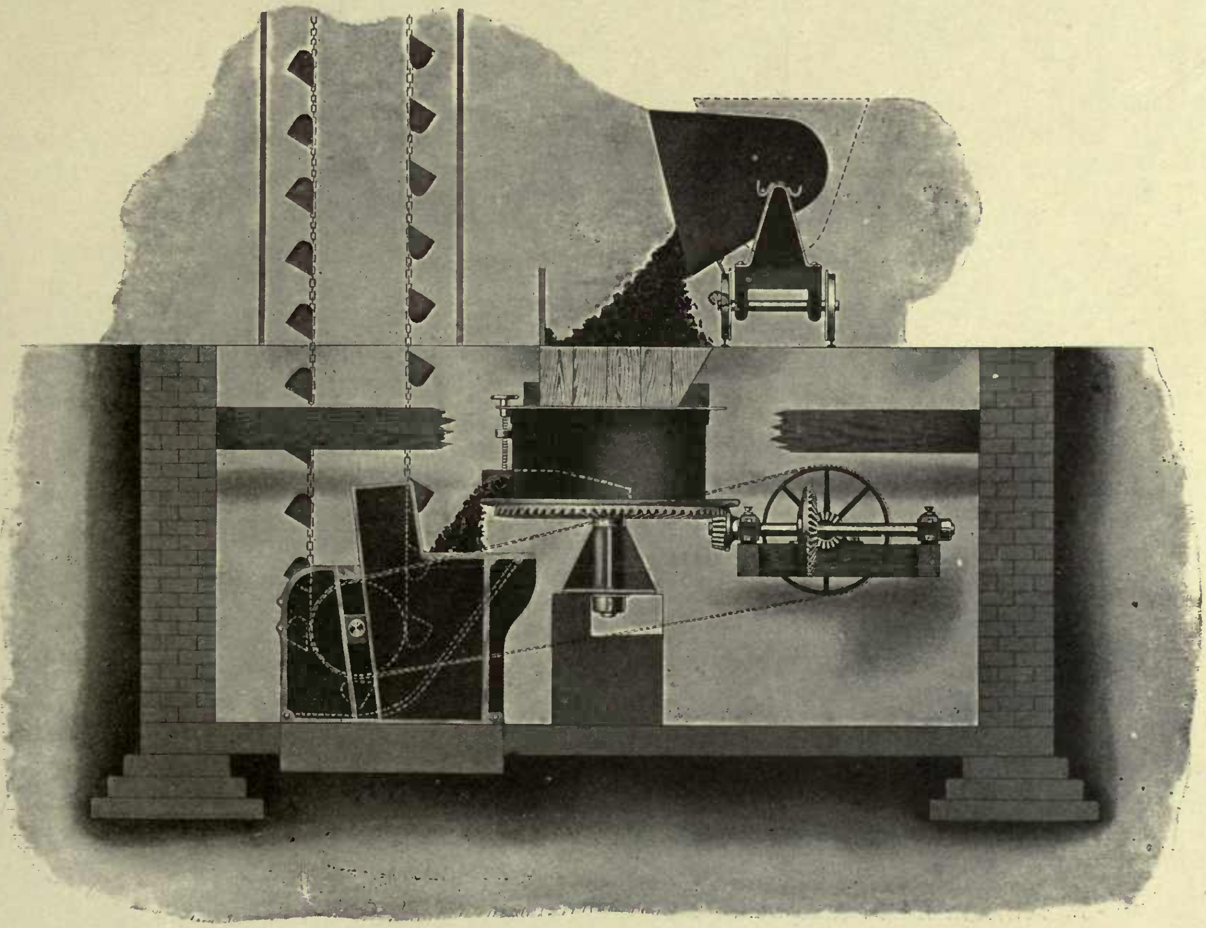


FIG. 17. Auto-Feeder and Bucket-Elevator
Courtesy of Sutcliffe, Speakman & Co. Ltd.

and sand in separate hoppers, the bottom of each hopper being formed by a conveyor-belt. The top of each belt is adjusted at such a distance below the bottom of the hopper that the depth of material on the belts can be made proportionate to each other. The lime is carried by its belt to a convenient position above the sand-belt and the lime falls on the sand in a perfectly regular stream. This arrangement and that shown in Fig. 17 are both capable of being adjusted with great accuracy and are suitable for even the largest outputs.

Some firms find measurers unnecessary and that the workman can judge with

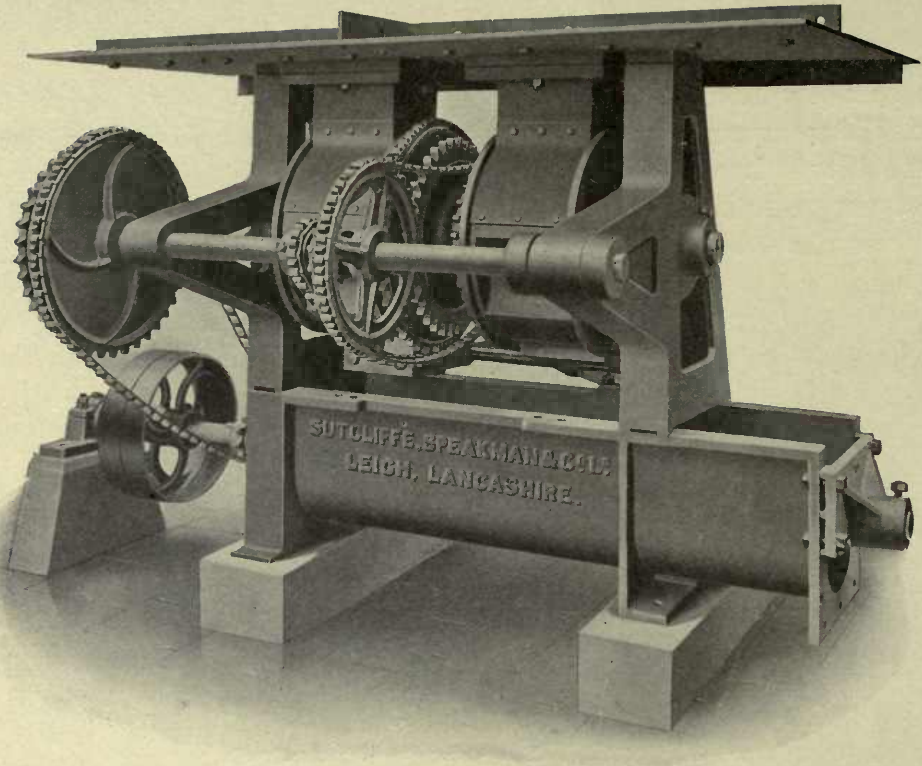


FIG. 18. Measuring Machine

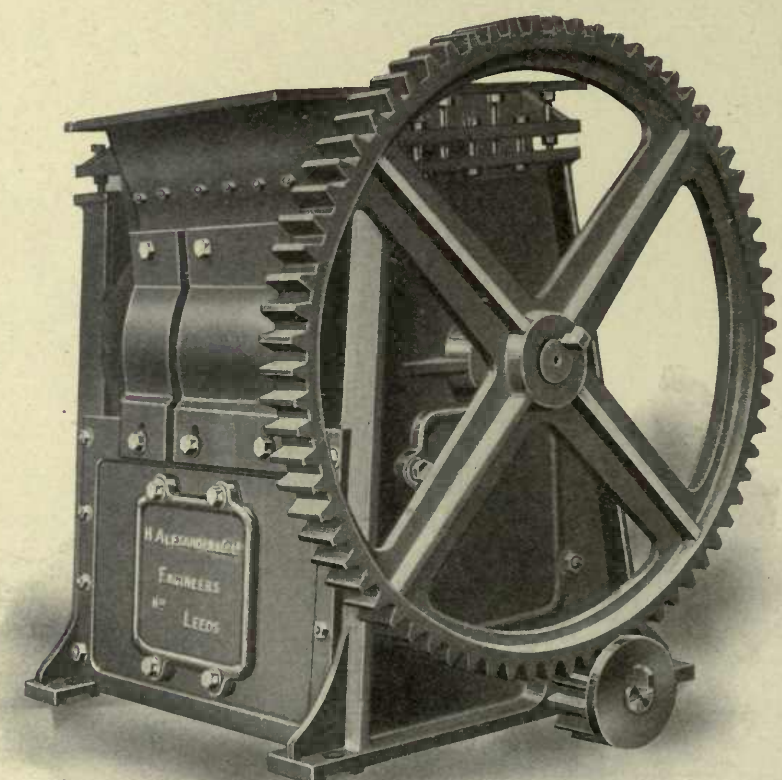


FIG. 19. Mixing Machine

sufficient accuracy the amount of lime to be added. The author does not recommend this arrangement, but if it is adopted, repeated tests of the lime in the bricks should be made in the manner described in the *Appendix.*

The water is almost invariably measured in a cistern which, on pulling a chain or otherwise operating a siphonic valve, will deliver the requisite number of gallons.

There is a scope for a considerable amount of ingenuity in the arrangement and construction of these measuring appliances, and most firms employ devices made according to their own ideas, but generally included in one of the appliances already mentioned. The essential feature of all such appliances should be the facility with which they can be adjusted to suit the changes in the moistness, etc., of the material, yet at the same time they must be so arranged as to be as " fool-proof " as possible, or serious damage may be done in the production of unsound bricks. In selecting a measuring appliance it is, therefore, wise to choose one with the greatest range of adjustment, but which may be " locked " in some way to prevent unauthorized persons from interfering with the adjustment. This applies equally to the means for determining the rate at which water is to be added to the mixture.

The quantities of each of the materials to be used must be ascertained by a preliminary test, but the correct amounts having once been found, they should be measured with the greatest care. Errors in this stage of the manufacture may prove to be serious at a later stage. As previously stated, the ordinary proportions are :

Aggregate	80–90 per cent.
Lime	6–10 ,,
Water	5–10 ,,

CHAPTER IV

HISTORICAL AND OBSOLETE METHODS

THE history of the various attempts to produce bricks and blocks from non-plastic materials is long and comprehensive. Some idea of this may be gained from a perusal of Chaps. I and IX. As far as lime-sand products are concerned it dates back to 1796, when *Major Pratt* made artificial mill-stones by burning a mixture of sand and lime at a red heat, though at a far earlier date German engineers had constructed blocks of hydraulic lime and sand. The earliest patent for bricks of this nature is that of *Kent*, who, in 1810, used $8\frac{1}{4}$ parts of lime and $91\frac{3}{4}$ parts of sand. Kent allowed his bricks to harden in air—a process requiring several months.

The great difficulties in the manufacture of lime-sand bricks have been chiefly of four types and are concerned with :

(*a*) The complete hydration of the lime.

(*b*) The production of a uniform paste.

(*c*) The formation of well-pressed bricks.

(*d*) The hardening of the bricks.

Of these, the first has proved by far the most difficult to inventors ; the second somewhat less so ; the difficulties with regard to presses have been overcome by British engineers,* though several Continental firms still offer presses which are unsatisfactory in several respects. The hardening of the bricks has been the subject of numerous patents, but all the more important of these have been abandoned or have expired in the ordinary manner by the lapse of time. At the present time there is, therefore, no patented method of hardening which is worth the consideration of the prospective manufacturer of non-plastic bricks.

The facts all go to prove that the best and most satisfactory method of hardening non-plastic bricks is by the use of autoclaves and steam at high pressure as patented in England in 1866 by *Van Derburg*, adopted about four years later by *W. Michaelis* in Germany, and described in Chap. VIII. If reasonable care is taken there are no serious difficulties in the use of this process, and the results are so invariably satisfactory that it is rapidly replacing all others. In fact, there has been so much swindling and misrepresentation in the lime-sand brick industry in the formation of fake companies and the abuse of Letters Patent, that those people who con-

* Mr. Herbert Alexander's Hercules Presses (Fig. 38) were in use in Germany and France in 1895 and are still used there and elsewhere. Most of the more recent German and French presses are only slight modifications of this type of press.

template investing in this industry cannot be too careful in avoiding unscrupulous company promoters and others who make untrue claims for processes or machinery. The services of a reliable and entirely impartial and independent authority should be requisitioned, but care must be taken to ensure that he really is independent and not a secret agent of the parties concerned.

A brief account of the chief historical and obsolete methods will show some of the difficulties which have had to be overcome. It is also important to note that several well-known patentees have never used their patents in actual practice, though they have issued licences for them at heavy fees or royalties. It must be clearly understood that no patents exist for the processes of manufacture which are worth consideration. Several pieces of machinery are patented, and the use of these machines is often advantageous, though not always essential to success. *S. Neffgen*, for instance, in 1891 patented the use of air saturated with steam and applied at the temperature of boiling water, but in actual practice he used the exhaust steam from an engine, and so followed the original directions of Michaelis to use steam. The low pressure of the steam necessitated keeping the bricks in the autoclave for forty-eight hours or more. This process was at one time used in a number of German works in connection with *Becker and Klee's* method, which consisted in grinding the lime with eight times its weight of sand and adding sufficient water to enable the bricks to be pressed properly. The bricks were then stacked in autoclaves and hardened by means of a mixture of air and exhaust steam.

H. Olschewsky in 1894 patented the utilization of the heat developed in slaking the lime for hardening other bricks, but in practice this was never sufficient and steam had always to be applied.

The firm of *Gebr. Pfeiffer* purchased the rights of Olschewsky's patent for slaking the lime and attached boxes to the cars carrying the bricks in the hardening chamber. Separate waggons for the lime were also used for a time but did not produce a uniformly hydrated product. Later, Olschewsky adopted an idea patented by *Jäger* and consisting of a rotary hydrating drum. A mixture of sand and lime was passed through this, water being added through a perforated pipe in the axle of the drum in rather larger quantity than is sufficient to hydrate the lime. The completion of the hydration is judged by reading a pressure-gauge attached to the drum. As the lime and water combine, the pressure rises and may reach sixty pounds per square inch, then gradually declines to zero as the steam is absorbed by the lime. It will be observed that Method E (Chap. V), in which steam is used as well as water, ensures a more complete hydration than water alone and, for this reason, is preferable.

The chief value of Olschewsky's hydrating drum lay in the facility it offered for the use of wet sands. The heat evolved by the hydration of the lime evaporated a considerable quantity of water, and so effected a partial drying of the sand whenever this was required. It should be observed that Olschewsky held very exaggerated opinions as to the validity of the patent under which he worked and considered that the use of any drum or cylinder, either open or closed, was an infringement of his rights. This led to much vexatious litigation, especially in Germany.

P. Kleber in 1897 patented the use of hydrochloric acid, but never applied it seriously ; on the contrary, all plants working under his licence use the ordinary silo-process !

About this time, *Huennekes* took out patents both in Germany and the United States for a method in use in Germany at that time, which consisted in mixing the lime with part of the sand and grinding this mixture to a very fine powder. To give his specification a better appearance, this patentee claimed the use of silicate of soda in trays. This substance was so placed that it could take no essential part in the manufacture of the bricks. Huennekes failed to work his process profitably in the United States, but *L. F. Kwiatkowski,* who was one of his assistants, in 1904 obtained a patent (since allowed to lapse) for the simultaneous incorporation and pulverizing of the whole of the unslaked lime and part of the sand, and thereafter adding the remainder of the sand. He also claimed the subjection of the moulded mixture to the action of "superheated salts—impregnated steam under pressure." The chemical salts used to impregnate the steam are not specified, and this part of the specification, like the use of silicate of soda by his former master, was only included to give an appearance of novelty to the claim. This method has become widely known in the United States as the "Division method," but, as a matter of fact, no firm has any right to reserve it for their own use under any Letters Patent. This has been conclusively shown as the result of extensive litigation in the United States. In 1912 Kwiatkowski—who had in the meantime changed his name to *Kaye*—came to England, and after numerous efforts to persuade various people to take up his process, he became associated with the British Silicate Engineering Co., and in 1913 took out a fresh patent, which is of doubtful technical value. The only difference between this and the 1904 patent is that :

(*a*) In the 1904 patent the lime and moist sand are mixed and ground simultaneously.

(*b*) In the 1913 patent the lime is crushed and then mixed with the moist sand. After being stored for an hour the mixture is ground—more water being added, if necessary, to complete the hydration.

Similar considerations and facts to those which rendered Kwiatkowski's American patent invalid apply equally to the 1913 patent, and there is the additional objection that the limits stated with regard to the amount of moisture which may be present render it extremely difficult to make satisfactory bricks from quicklime by adhering closely to the operations in the specification. A further claim is made for the addition of Portland cement to the sand, but this is invalidated by its use (to the author's knowledge) both in this country and in Germany more than five years before Kaye's and the British Silicate Engineering Co.'s claim was patented.

Many other claims than those mentioned in this volume and unworthy of being described in detail, may be found in the patent specifications of the leading countries. In almost every case these claims show an amount of ignorance of the chemical and other principles involved in the manufacture of lime-sand bricks which would be ludicrous if it were not for the enormous financial losses which have been incurred in the exploitation of these patents—losses which have been so great in some instances as to be among the wonders of modern industrialism. The use of a small quantity of asbestos is only one of many instances where claims made on behalf of an entirely unnecessary and inert material have benefited the "inventor," but have ruined the firms which purchased the discovery.

The chief lesson to be learned from the study of the various processes used in the manufacture of lime-sand bricks is that there is no patent which covers the *process* of making sand and lime into bricks. The only really valid patents apply to some special machine to be used in the manufacture. Large sums of money have been obtained from the public by unscrupulous promoters who have wrongfully created the impression that they were selling some patent which covered the actual process of making sand and lime into bricks. In every case investigated by the author, the patents under which these sums of money have been obtained for processes as distinct from machinery have been rendered nugatory by anticipation, prior publication, or previous use.

Schwarz and *Meurer* consider it essential to dry the sand before use in order to ensure that a definite quantity of water can be added and to provide for the whole of the lime being hydrated. Any unhydrated lime will spoil the bricks by causing them to "blow" or crack, and with a damp sand containing an unknown or variable percentage of water it is almost impossible to add the correct amount of water. If too little is added the bricks will "blow" or crack, whilst if too much is added the bricks will lack uniformity and cannot be pressed properly. Drying the sand obviates this difficulty by permitting the use of a definite amount of water which is neither excessive nor insufficient, but the cost of drying is usually prohibitive. Schwarz and Meurer provided the mixing-mill with a steam-jacket to hasten the rapidity of the hydration. The sand is seldom dried in actual practice, but the employment of a steam-jacketed mixer will often be found to be very useful for ensuring the hydration of difficult materials, such as some slags and clinkers, and in supplying the presses with a slightly warmed paste. Its use is therefore recommended on p. 67.

Slag-bricks

In the past many methods have been tried for the production of bricks from blast-furnace slag, but most of them failed because the bricks were too rough or too porous, as those who attempted the manufacture were unaware of the conditions required. As shown later these difficulties have now been overcome, but a short note on the failures is of interest. Thus, *John Payne*, an Englishman, was the first who succeeded in utilizing blast-furnace slag for making big solid blocks—up to three tons in weight—which were successfully used for making river and canal embankments. According to his method of making blocks, patented in 1728, the liquid slag was first thoroughly worked through, by means of a shovel, in order to allow any air- or gas-bubbles to escape, whilst at the same time sand or crushed slag was added. The doughy mass thus received was pressed into cast-iron moulds lined with sand. When hard, the blocks were withdrawn from the moulds and allowed to cool down slowly in a bed of sand mixed with charcoal-dust.

This method of making blocks could, however, only be used for utilizing blast-furnace slag high in silica and poor in lime, *i.e.* principally for slag resulting from blast-furnaces worked with charcoal, for reasons not necessary to be explained.

Fritz Lürmann, when at Osnabrück, was the first who recognized and also utilized the hydraulic properties of granulated basic blast-furnace slag for making bricks by mixing granulated blast-furnace slag with lime-cream and pressing this mixture into moulds. The lime thus combining with the free silica in the granulated slag served as a cement, and the bricks became hard on free exposure to the atmosphere within about six to eight weeks. The slag bricks produced at the beginning were, however, of inferior quality, and could, on account of their insufficient strength, only be used for masonry of minor importance. It was also found that during the time of hardening many bricks cracked and fell to pieces.

Considerable improvements were made later, namely :

(*a*) An automatic feeding apparatus was provided having for its purpose the maintenance of the proper proportions between the granulated slag and the slaked lime, ascertained by experiment, instead of leaving these proportions to be adjusted, as before, by the workmen employed. In general, it was found that an addition of 150 lb. of dry slaked lime to 850 lb. of granulated slag, containing on an average 20 per cent. of water, answered the purpose pretty well.

(*b*) Appliances were employed by means of which an intimate mixture of the slaked lime and granulated slag was obtained.

(*c*) A press, especially constructed for making slag-bricks, was employed. In the first instance the maximum pressure was raised to about 3500 lb. per square inch. Secondly, the press was constructed in such a way as to do its work with a gradually increasing pressure instead of, as before, by means of a heavy shock. The latter had a double advantage: first, the high pressure was transmitted throughout the interior of the brick, which is not the case when the press is worked with a shock ; and secondly, all superfluous moisture was squeezed out.

(*d*) In order to avoid, as much as possible, any loss from bricks bursting, on account of particles of unslaked lime being entangled and enclosed in the interior of the brick, the slaked lime had, before use, to pass through a ball-mill, where it was reduced to powder and intimately mixed, whereby the complete conversion of any free lime into hydrate of lime was ensured at a later stage of manufacture.

One such press, with its accessories, as mentioned before, produces about 2000 slag-bricks per hour, the whole requiring about 25 h.p. to drive it.

One slag-brick of ordinary size, manufactured in the way described, weighs on an average 8 lb. and has a maximum crushing strength of 1700 lb. per square inch.

The working expenses (lime, wages, repairs, and motive-power) usually average about 11*s*. per 1000 bricks of ordinary size.

A brick press, also constructed for making slag-bricks, was recently invented by *Paul Thomann* in Germany. This device consists of a small cylindrical sheet-iron vessel containing a mixer with screw-like arms of peculiar shape, in which the slaked lime and granulated slag are, owing to quick rotation, intimately mixed within a short time. The mixture then falls, by means of a hopper, into the brick press. The peculiarity of the latter consists in an arrangement by means of which the brick is formed in layers, each layer being hammered down separately, one above the other, until the brick-mould is filled.

Another method of making slag-bricks, still in use, consists in mixing one part of Portland cement with from four to five parts of granulated slag and pressing this mixture in moulds. The bricks must remain in the moulds for twenty-four to thirty hours after being pressed. As they are not allowed to harden in the open air they have to remain, after having been taken out from the mould, for six to eight weeks in a covered shed, well protected against sun and wind, where they are moistened from time to time.

The bricks produced in this way are of very good quality, but their cost of manufacture is very high, requiring also a considerably high initial outlay ; it can therefore only be recommended for making artificial stones of special size, staircase steps, slabs, etc.

The best slag-bricks so far as shape and dimensions, as well as great hardness and resistance to crushing are concerned, are made by grinding a portion of the slag with lime and mixing this with the remainder of the slag. This mixture is then pressed into bricks, which are afterwards hardened in an autoclave (Method *D*, p. 44), but the process described on p. 68 (Method *EII*) has been used in many works with complete satisfaction.

CHAPTER V

MIXING THE MATERIALS

SEVERAL methods of mixing the materials are available, but the following indicate the chief ones :

(A) Mixing the sand with lime which has previously been slaked with water.

(B) Mixing the aggregate, ground lime and water in the desired proportions and then conveying them to a silo in which the hydration of the lime is completed.

(C) Mixing the ground lime with twice or three times its volume of aggregate and putting this mixture in a silo. The remainder of the sand is added during a further or final mixing and does not enter the silo.

(D) Grinding the lime with twice or three times its volume of aggregate, mixing this with the remainder of the aggregate and then storing the whole in a silo until the hydration is complete. This is sometimes known as the *Division Method*, but no firm has any exclusive right either to the method or the use of this term.

(E) Treating the materials in a hydrator or hydrating drum with steam.

With regard to method A, there is a widespread opinion that the use of slaked lime is less effective than when the lime and sand are mixed and then treated with water or steam in a hydrator (method E). If the complete slaking of the lime can be guaranteed, the use of prehydrated lime may be satisfactory, but not otherwise. This may be secured to some extent by the storage of the material in bins or silos, as in the other processes. Another method, using prehydrated lime—sometimes termed the *Lime-putty system*—is satisfactory in tropical countries and in localities where freight charges are very high.

Method B is specially suitable for damp sands. No water is added, but the heat evolved by the hydration of the lime evaporates some of the excess of water in the sand and obviates the necessity of drying the latter unless it originally contained more than 10 per cent. of water. It is, however, very difficult to obtain a uniform mixture as the wet lime tends to accumulate instead of being properly distributed.

Method C is an improvement on B for most aggregates, but it is inferior to method D especially in the case of lime-sand bricks. It gives a reasonably uniform mixture, but the lime—when ground separately—is coarser than that obtained in method D and is therefore of lesser covering power.

Method D is unquestionably the best of all the methods in which the silo is used, and its products are fully equal to those produced by any other method of mixing.

Method E is chiefly used where a very large output is required and is especially valuable for hydrating the lime found in all destructor clinkers, which is very difficult to slake in a silo at a sufficiently rapid rate.

The prevailing sentiment is in favour of the use of silos wherever possible, but for very large works and for materials such as slags and clinkers which contain free lime, the hydrating drum is advantageous. Some firms combine the two methods and discharge the contents of the hydrating drum into a silo. This may be regarded as the ideal method and one which overcomes all the disadvantages of the others, but it is more costly to operate than the simple silo system, and for that reason is only slowly coming into use. If the number of weak, damaged, or imperfect bricks obtained in the course of a normal year's working by each of the foregoing methods is compared, and the cost of these charged on to the cost of making the saleable bricks, it will be found that in almost every case the use of a hot hydrating drum followed by a silo (method E), is really the lowest in cost of production. Unfortunately for themselves, many prospective makers of lime-sand bricks do not regard the matter in this businesslike manner, but devote all their attention to the installation of a plant at the lowest possible first cost. Such a policy is seldom wise, and it usually proves the most costly of all methods in the course of a few years' working.

At the same time it should be observed that the local conditions have a great influence in deciding which method, or what modification of it, is best in any given locality, and for this reason the prospective manufacturer will find it to his interest to consult a specialist who is quite independent of the makers of the various machines and whose advice can, therefore, be relied upon as being entirely unbiased and impartial. In this way, and only in this way, can true economy be assured.

METHOD A. The successful manufacture of bricks by means of lime which has been slaked with water before use is confined to comparatively few plants, notwithstanding its simplicity. There are various reasons for this, one of which is the slightly higher cost of installation, whilst another is the absence of anything patentable in the process.

The essential feature of this method is the manner in which the hydration of the lime is effected. As previously explained, there is sometimes an uncertainty as to whether the whole of the lime has been hydrated when any of the other methods are used, and though this risk may be reduced to insignificant proportions with most natural sands, this is by no means the case when some slags and all destructor clinkers are used.

Various methods of hydration may be used. One consists of two boxes, placed one above the other, with a cylindrical basket or cage, made of round iron bars in the upper one. The lumps of quicklime are run into this basket, the chamber being heated by steam and water being injected into the basket. As the lime slakes (hydrates) it becomes powder and falls through the bars into the box beneath, where it is mixed with mixing blades so as to distribute the moisture as evenly as possible. The cage is frequently made to revolve in order to facilitate the removal of the slaked lime.

Another hydrator (the Clyde) requires the lime to be crushed to a coarse powder in a disintegrator. This hydrator consists of a revolving pan which is fitted with a number of scrapers, which turn the lime over each half revolution of the pan. The water is supplied through a sprinkler from a dosing tank, which holds just sufficient water to slake the lime in the pan. All access of water, due to accident, is thereby avoided. When the hydration is complete, which only requires a minute on account of the speed at which the pan revolves, a special scraper is lowered, and the material discharged through the centre of the pan into a receiving bin, placed immediately over the sieve.

A very convenient hydrator consists of a hollow drum mounted with its axis horizontal and fitted with mixing blades on the horizontal shaft. This cylinder is closed with a loose-fitting lid. The charge of lime and water is thrown into the drum and the mixing blades are rotated for some minutes until the boiling ceases and the lime is hydrated. The blades are stopped and the lid opened and the contents of the drum are discharged on to the sieve. The lid being loose, there is no serious amount of steam pressure developed, a comparatively tight construction suffices for the drum and very little power is required.

If too little water is present in the mixture, or the temperature reached in the hydrator is too low, some of the lime will remain uncombined with water, and this will, later, make the bricks crack or " blow." If too much water is used, the paste will be too soft and will tend to unmix. The facts point to the use of cold water as being an unsuitable hydrating agent, but steam * has been found to be equally powerful and yet to be free from the disadvantages of liquid water.

For instance, an excess of liquid water is retained by lime, forming a paste or putty which can only be imperfectly mixed with the aggregate, but an excess of dry steam will escape completely from the hot lime, leaving it in a dry and perfectly hydrated condition. Hence, while it is impossible to add more than a limited amount of liquid water in order to hydrate the lime, if the water vapour (steam) is used, the quantity which can be employed is unlimited so long as it is maintained at a sufficiently high temperature to prevent it condensing and so wetting the lime. At the conclusion of the hydration the excess of steam is allowed to escape.

By hydrating with steam under pressure, the manufacturer can be absolutely certain that every particle of lime has been hydrated and yet no excess of water is

* It should be observed that dry steam alone cannot be used for hydrating lime ; liquid water appears to be absolutely necessary as well as steam. At the same time, water alone is either uncertain with regard to the completeness of the hydration or it makes the lime too wet. Hence, the use of both water and steam consecutively.

present. The variations in the dampness of the sand or aggregate used do not then affect the hydration of the lime and the difficulties of the silo method are avoided.

A further advantage of steam hydrating is that the use of silos may be avoided and a considerable saving in the cost of construction effected. The apparent cost of hydrating by steam is greater than by the silo process, but if the interest on the capital expended in the erection of the silos is taken into account, it will be found that the use of a steam hydrating drum does not really cost any more than the use of silos and its action is far more reliable.

To effect the hydration by steam under pressure a hydrating cylinder is required. One of the best patterns consists of a jacketed steel cylinder 20 ft. to 30 ft. in length, and 5 ft. to 7 ft. in diameter, arranged to revolve on rollers about five times per minute. The cylinder must be sufficiently strong to resist the action of the steam under a pressure of at least 150 lb. per square inch, but is fitted with a safety-valve to blow off at 60 lb. per square inch. Powerful mixing blades are fitted inside the cylinder and the jacket is heated by steam. The latter arrangement prevents the cylinder being cold in use, as the heat from the slaking lime would then be wasted in heating up the cold metal, and an imperfect formation of silicate would result. The empty cylinder is first heated by blowing steam into it, and when the right temperature is reached, a charge of sand or aggregate and lime in suitable proportions for making bricks is then poured through the opening. The cylinder is then closed and the mixing blades set in motion ; this is continued for a few minutes to break down the lumps of lime and partially mix the materials. A measured quantity of water is then run in and the steam produced soon sets up a pressure which is indicated on the steam gauge. This is watched closely ; if it rises above sixty pounds the safety-valve should be released automatically or a relief-valve must be opened until the pressure is at sixty pounds. Should there be a deficiency of steam pressure from the reaction of the lime in the water, a steam-valve is opened to admit steam into contact with the contents of the cylinder. When a suitable pressure (usually sixty pounds to the square inch) is reached inside the apparatus, it is maintained constant for ten to twenty minutes, the mixing being continued the whole time. It will be found that the amount of steam admitted must be gradually increased to compensate for that removed by combination with the lime and the end of the hydration may be told by the pressure rising to that in the steam-pipe. The necessary time having elapsed the steam is cut off, the lime allowed to cool, and is then taken away to be used.

The ideal hydrator must not only secure the complete admixture of the lime and water; it must deliver a material which is quite free from unslaked lime. Any particles of quicklime in the hydrated material will cause swelling in the bricks and may even cause them to "blow" or to rupture. After the lime has been hydrated, it must be screened in order to remove any small pieces of inert material and any coarse particles of unhydrated lime.

Screens. Various types of sieve may be employed, but as the lime-dust is very objectionable it is desirable that some closed form should be used. The ordinary method of fixing a revolving screen in a wooden casing is not very satisfactory, a plain screen being preferable. In one of the best types of screen the material is fed into a trough which runs along the top of the screen, and contains a spiral conveyor which distributes the lime evenly over a weir and spreads the lime over the whole width of the screen. The screen, which may be of perforated sheet or of wire gauze, is fixed in a wooden or iron frame and suspended. Just above its upper surface is a cover, and penetrating through this is a series of projecting bars attached to the screen ; these form the anvils on which a series of hammers strike, thus giving ample vibration to the screening surface.

Some firms use a piano-wire screen, consisting of a series of steel wires tightly stretched and arranged side by side, the distance between them being arranged according to the fineness of the product required. As these wires are stretched so tightly, the material falling on to them causes them to vibrate, and in many instances renders the use of a mechanical vibrator (hammers) unnecessary.

Screening the product eliminates many of the incompleted hydrated particles, but, unless the screening surface is very large, it seriously reduces the output, and no screen can be made sufficiently fine to remove every particle of the unslaked lime. For this reason, even when hydrating machines are used, it is generally necessary to store the material in silos in order that the slight excess of water present may hydrate any quicklime particles which remain. The screened, hydrated lime may be mixed with a suitable proportion of sand and water, the mixing being continued until a paste of a consistency suitable for pressing is obtained.

Mixing. This may be effected in a trough-mixer (Figs. 23–26), or preferably in a pan-mill. If a pan-mill (Fig. 28) is used, the sand, hydrated lime, and water may be mixed together in batches—each batch requiring about fifteen minutes, after which the material is taken direct to the press. Hydrating the lime before use is an excellent idea wherever there can be any doubt as to the completeness of the hydration, but it is essential in all cases that the lime should be stored for some hours after hydration, and before the bricks are made, as time is required for the reaction between the lime and water to complete itself.

Lime-Putty Method. Where the sand is exceptionally dry—as in some tropical countries—or where a clinker or other dry material which contains no free lime is used, the *lime-putty* method is satisfactory and enables a cheap plant to be used. The lime is slaked with an excessive quantity of water, is made into a paste similar to that used by plasterers, and is stored for a sufficient time for the hydration to be complete. The sand, or other aggregate, and putty in the proportions of about 5 to 1 are then fed into a pan-mill (Fig. 28) and thoroughly mixed. The mixture is then taken to the presses and treated as described on page 72, *et seq.*

As bricks made with lime putty are softer than those made by other methods, it is desirable to use narrow hardening chambers and not to stack the bricks so high on the cars.

It is essential to the use of lime putty, that the sand should be dry, as the putty itself contains so much water. If damp sand is to be treated by this process a sand dryer will be required and the use of such an appliance generally makes the manufacture of bricks unprofitable.

The best bricks obtained by this method are those in which a dry, coarse, sharp sand is used. They are sometimes termed *mortar bricks*.

Instead of making the lime into lime-putty it is sometimes slaked in small

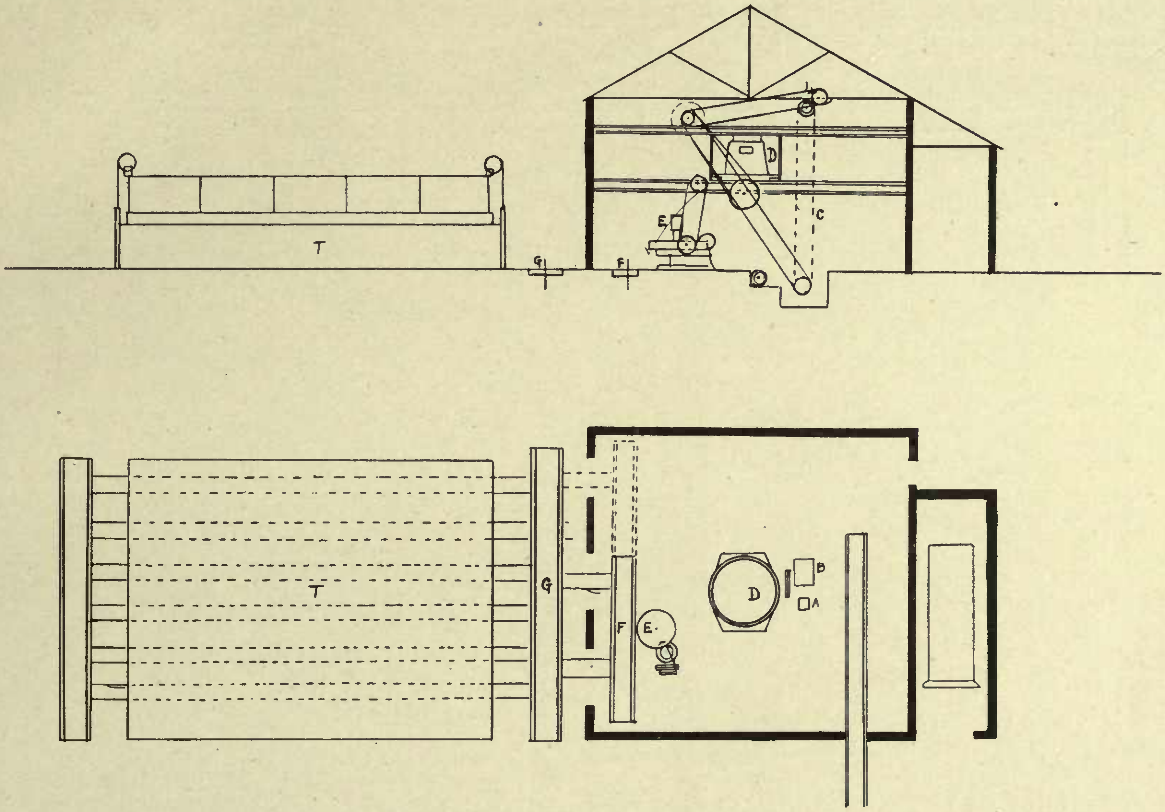


FIG. 20. Plant for Method A

waggons in the hardening cylinders, but in this method it is impossible to avoid lime spots, owing to the difficulty of hydrating the lime completely.

Plant. An arrangement for using Method A for slag bricks is shown in Fig. 20. Messrs. Sutcliffe, Speakman and Co. Ltd., claim that it was originally introduced by them and it has proved highly successful as a means of utilizing an otherwise troublesome material. It is extensively used on the Continent. In the plant illustrated, the lime used is slaked lime in the proportion of about 8 per cent. of the weight of the slag. The granulated slag is brought to the works in waggons and tipped into the automatic feeder, B, whilst the lime is tipped into the smaller one, A. These feeders can be regulated to give the required proportions of the material and to feed the elevator, C, in a regular manner. The latter raises the mixture into a double deck mixing mill, D, in which the slag and lime are thoroughly mixed and incorporated. The mill continuously discharges the materials into the feeding-pan of the press, E, which converts them under a heavy pressure into bricks. In front of the press is a double transfer car, F, running on a special track. Steel plates are placed on supports on the transfer car and when one is loaded the car is pushed on the track so that the other supports come in front of the press with a plate which is now loaded in its turn. For removing the plates from the brackets on to the transfer car, a special lifting waggon is run between the brackets and underneath a plate, the latter being lifted off by turning a handle and raising the top of the

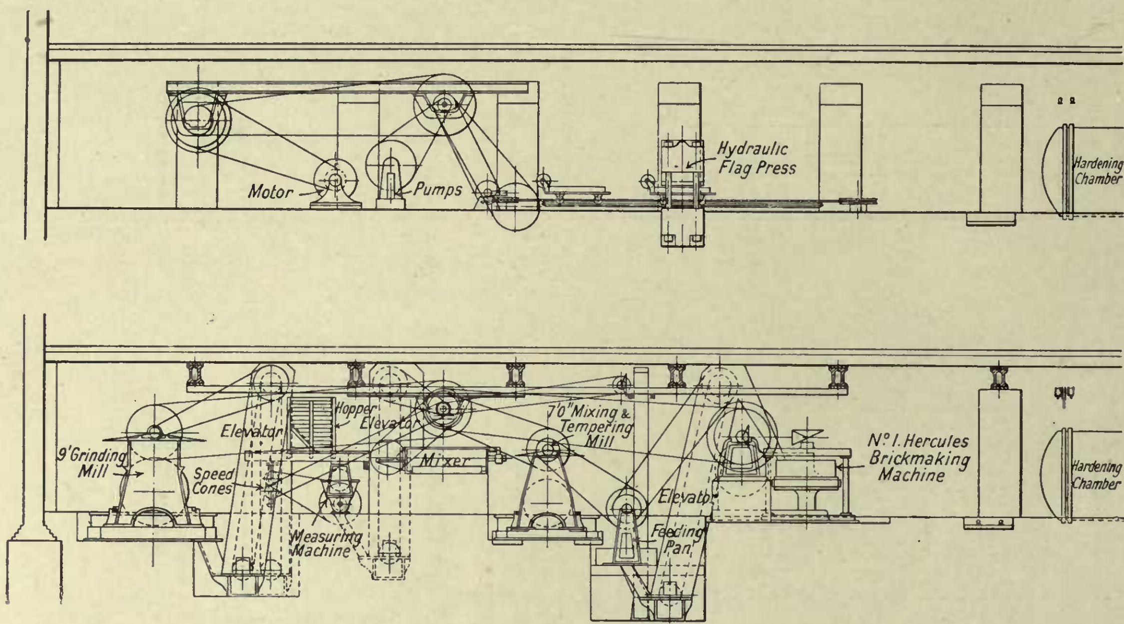


FIG. 21. Plant for making Bricks and Flags (Method A)
Courtesy of H. Alexander & Co. Ltd.

waggon (Fig. 22). This is then pushed on the single transfer car, G, running on another track in front of the tunnels, T, which are made of masonry, and on the side walls there are projections on which the plates charged with bricks are deposited by lowering the movable part of the waggon on which they have been taken into the tunnels.

For an output of 20,000 bricks per day, nine such tunnels are desirable. When a tunnel is filled with plates charged with bricks, the door is closed and steam of low pressure (atmospheric) introduced into it. After about twenty-four hours in the tunnels, the bricks are properly hardened and ready for use. In removing the bricks and plates from the tunnels the same waggons are used. Broadly speaking, where prehydrated lime is required, method E (p. 67) should be used. Another arrangement of plant (by H. Alexander and Co. Ltd.) is shown in Fig. 21.

The chief *disadvantages* of Method A are the possible presence of unmixed lime, (which forms disfiguring white spots and may cause the bricks to crack or blow); the time required to prepare the lime-putty (if used) and the difficulty of mixing the wet, slaked lime with the aggregate. Notwithstanding these drawbacks, the method is useful in certain conditions such as those previously mentioned. Its chief *advantage* is that it entirely prevents all the defects which follow the use of imperfectly hydrated lime (*see* p. 41).

In localities where steam-hydrated lime can be purchased at a suitable price from the lime-burners—as in some parts of the United States—a simple modification of method A is excellent.

METHOD B. This consists in mixing the various ingredients together, placing

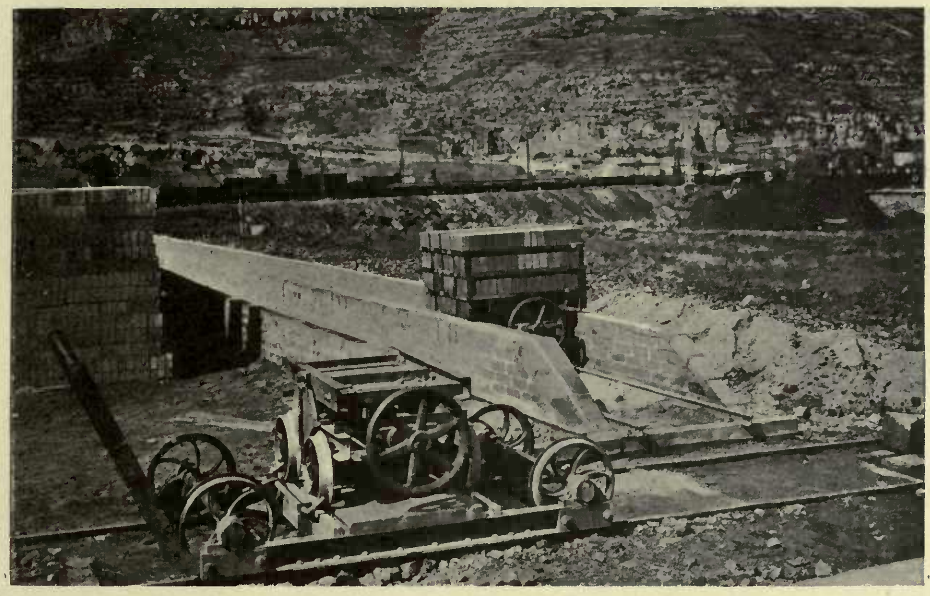


FIG. 22. Special Lifting Waggon
Courtesy of Sutcliffe, Speakman & Co. Ltd.

in a silo until the lime is fully hydrated and then passing the contents of the silo through a further mixing machine, preferably a pan mill.

The *Preliminary Mixers* are usually of the open trough type so well known in the manufacture of clay bricks, and consist of a trough in which rotates a shaft provided with blades set at an angle so as to cut into and mix up the material, at the same time conveying it towards the opposite end of the machine to that at which it entered. The length of this mixer must be sufficient to produce a uniform mixture of sand and lime. It is usually better to have two shafts in the trough, the blades of each working between each other so as to secure a better mixture than is usual with single shaft mixers. One shaft should revolve twice as fast as its fellow so as to secure the maximum mixing power.

The angle of the mixing blades on the shafts is also important. It must not be so steep that the material is conveyed through the trough too quickly, nor, on the contrary, must it be so small that unnecessary power is lost by the material travelling forward too slowly. To a large extent the angle must be made to suit the material,

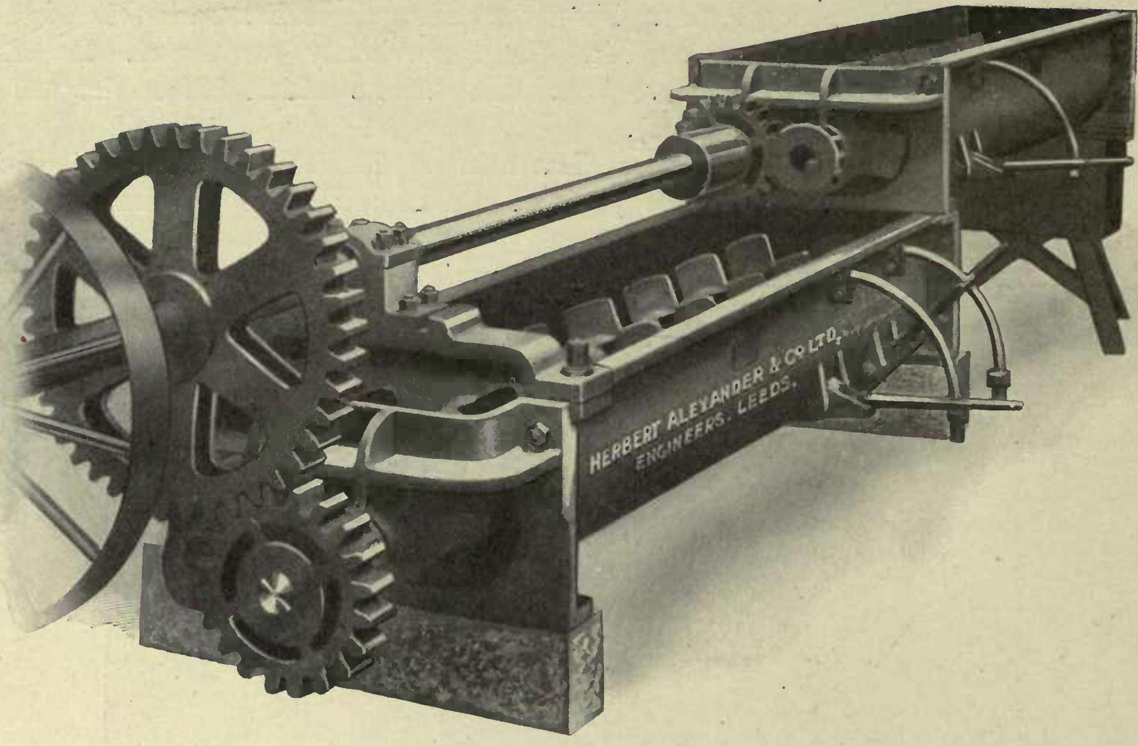


FIG. 23. Open Mixer

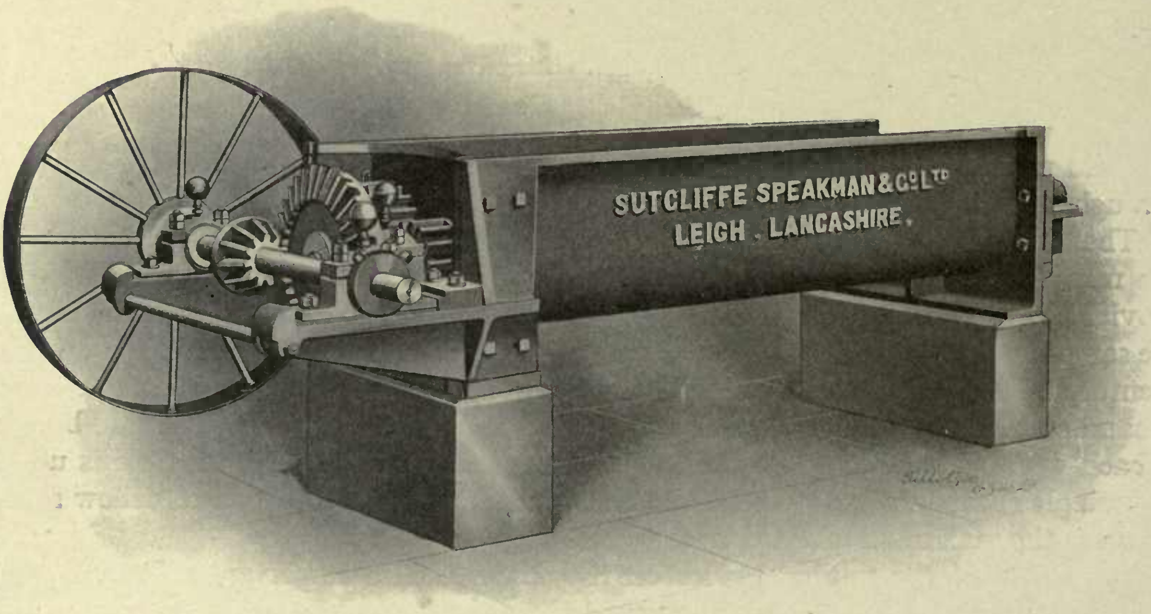


FIG. 24. Differential Trough Mixer

and as this is a matter for experiment, it is best studied in conjunction with the makers of the machines. The mixer may with advantage be heated by steam.

If properly designed and constructed, differential mixers of this type are highly efficient and, being comparatively simple machines, they have proved very satisfactory.

The measured quantities * of aggregate and lime are fed into a pug mill or open mixer (Figs. 23 to 25) of such a length that on passing out of this machine the two materials are well mixed. This mixture is then passed into a second pug mill of a similar pattern, and it is here mixed with water which hydrates the lime and raises the whole mass to a high temperature.

FIG. 25. Patent Steam-heated Mixer
Courtesy of Sutcliffe, Speakman & Co. Ltd.

In some works only one pug mill about 6 ft. in length is used, particularly where the sand is so damp that no additional water is required, but with dry sands a more uniform distribution of lime is effected by the use of two mixers as described above.

Instead of a trough mixer a batch mixer (Fig. 26) is sometimes used; this is similar to the double cone mixers used for concrete.

A still better arrangement is the use of a wet pan (Figs. 28 to 31), which effects a much better coating of the grains with lime than is possible in any other form of mixer, but the cost of its operation is such that its use is generally confined to the final mixing of the material, *i.e.* that which comes from the silos (*see* pages 54 to 56).

The position of the preliminary mixers is important. As the elevation and transport of the wet mixture is more difficult than that of the various materials separately, it is usually best to place the mixers above the silos and to lift the prepared but unmixed materials by means of suitable elevators (Figs. 5 and 17). If the site permits the erection of an inclined track from the sand pit to the mixers, the sand may be hauled up this track in waggons each holding about half a cubic yard, but in the case of clinkers and other materials which require crushing, a bucket elevator (Fig. 32) will be necessary to raise the material to the mixers.

Granulated slag may conveniently be tipped into an automatic feeder (Fig. 17) and elevated from this in buckets to the preliminary mixer.

Silos. The original style of silo consisted of a brick chamber with an opening beneath, out of which the material was pushed with a rake or shovel. The workman had frequently to climb inside this structure and to work the material down

* For measuring machines see p. 36.

by hand. Whilst some of these brickwork silos are still in use, most of the newer works employ silos constructed of steel, and of such a shape that the material falls to the exit without any assistance unless the material becomes abnormally adhesive.

Circular silos with a conical bottom have been used by a number of firms, but are not very satisfactory, as the material is difficult to remove from the cone-shaped portion.

The best form of silo is that of a long **V**-shaped trough, with slides at the bottom for the exit of the material; beneath these runs some form of conveyor to take the material in a regular stream to the mixing mills. Some firms use silos with vertical partitions (Fig. 27) so as to keep each day's supply of material separate. Except that these partitions strengthen the silos, they are of little value, and may often be omitted with advantage, the material being fed into the silo at the opposite end to that at which it is drawn out. By thus using a single bin (if not too large) the adhesion of the material is greatly reduced, and labour is thereby saved.

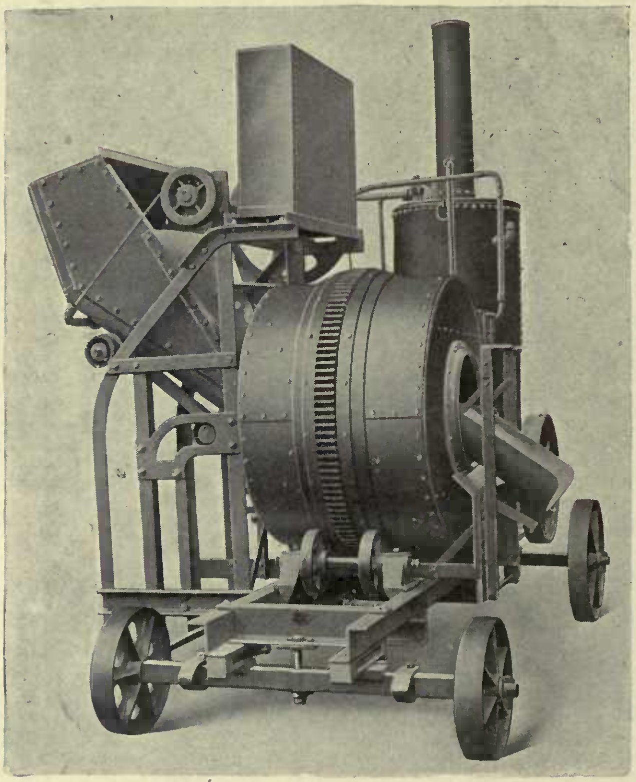


FIG. 26. Victoria Batch Mixer
Courtesy of T. L. Smith & Co. Ltd.

Deep, narrow bins are preferable to wider ones, as the mixture is usually very sticky, and must be pushed down wide bins with a spade.

A convenient size is a silo 25 to 30 ft. high and 8 to 15 ft. square, and whilst the size must naturally be arranged to suit the output, it is often better to have several silos of the size mentioned rather than one very large one.

The silos should be provided at the bottom with an automatic emptier which supplies a regular amount of material to the final mixer. A suitable form of emptier consists of a worm conveyor, which is more efficient and requires less attention than belts or elevators. At the same time a number of firms are quite satisfied with a continuous belt (say 16 in. wide) which runs beneath the silo just below a series of loose boards or planks which form the bottom of the silo. One or more of these boards is drawn out, the material is pushed with a hoe to break it down and put it on the belt; it is then taken to the secondary mixer and thence to the press. It costs a considerable sum—practically half a man's wages each week—to loosen the material in the silo, but this cannot easily be avoided unless a more elaborate method is used.

The silos are frequently built on the ground floor, the materials being delivered to them by elevators of various types. There has been a strong tendency in the more recently erected works to build the factory three stories high, the uppermost containing the grinding plant, the middle story the silos, and the ground floor the hardening cylinders. By this means the raw material can be taken up by a crane or lift to the top of the factory, and no other elevators are needed. This saves a considerable amount of power, as elevating appliances for continuous work are troublesome and wasteful of power.

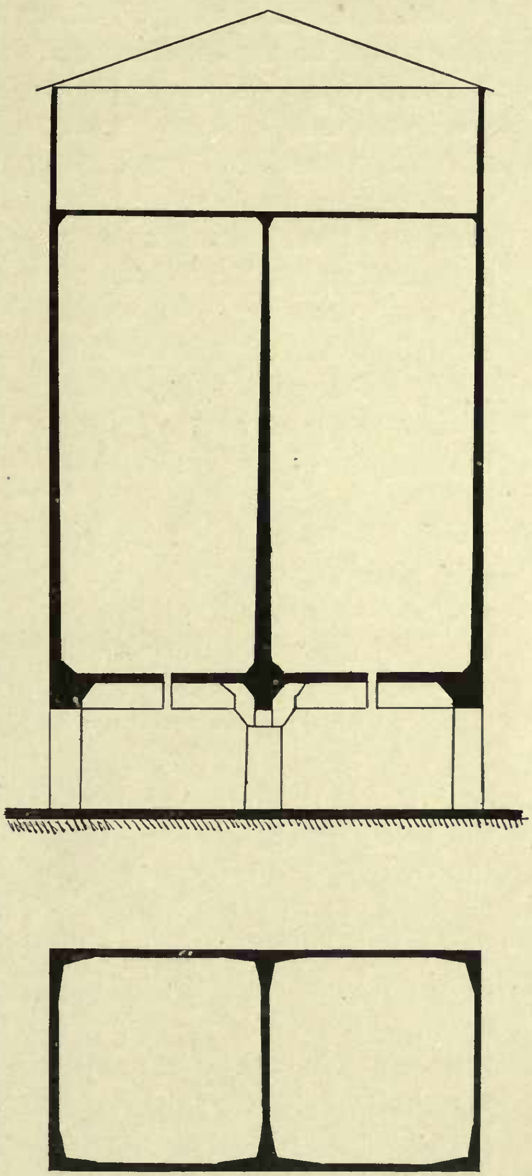


Fig. 27. Section and Plan of Silo

The details of the construction of silos are such that they are best left to firms experienced in the erection of such structures. As each silo may have to contain about 100 tons of material, it must be of ample strength without, at the same time, material being used wastefully in its construction. Silos built by amateurs are seldom satisfactory, and those built by firms specializing in this class of work prove cheaper in the end. Wooden silos were extensively used at one time, but the lower first cost was more than counterbalanced by the cost of emptying them, on account of the great adhesion of the wet material to wood.

The time of storage necessary varies from six hours to seventy-two hours, but is seldom more than forty-eight hours, except with a very slowly hydrating lime, or with an imperfectly mixed material. Clinker bricks require twelve to thirty-six hours in a silo on account of the difficulty of hydrating the free lime in the clinker.

If the period in the silos is too short, the bricks will swell in the hardening chamber, and cannot be readily removed. When in the silo any particles of lime which had not been hydrated in the mixer have an opportunity of combining with water and any chemical reactions of a hydrolytic nature have time to occur. Unless a silo is used there is always a tendency for some of the lime to remain unslaked, and these particles will, later, destroy the bricks in which they occur. If, on the contrary, the wet material is stored for a reasonable time before being made into bricks, the chemical action between the lime and the water will occur under conditions where it can only do good and not harm, and at the same time an opportunity is given for the more even distribution of the water throughout the mixture.

Another important feature in the use of a silo is that when any lime in it hydrates it swells to several times its original bulk. Under the pressure so produced, the soft lime-paste is slowly squeezed into the voids between the grains of aggregate. No such phenomenon can occur when slaked or prehydrated lime is used, and this is sometimes urged as a reason why the use of quicklime, which is mixed with the sand and then hydrated, is preferable to slaked lime. With the latter material it is almost impossible to coat all the grains of aggregate with lime except by a very thorough process of wet-pan treatment, the cost of which is sometimes prohibitive of profit to the manufacturer of the bricks.

A further point in favour of the slaking of the lime after mixing it with aggregate is that the heat evolved during the combination of the lime and water increases the amount of colloidal silicate (p. 82), and so greatly increases the strength of the bricks.

It has been stated by those who are opposed to the use of silos that great difficulty is encountered on account of the material in the silo becoming compacted and adhering to the sides or bottom of the silo, so that great expense is incurred in breaking up the material and getting it out. The difficulty is greatest when the silo contains a product made by mixing the previously hydrated lime with sand and using a very large percentage of lime. Such a material is very sticky and sticks to everything. In some works it takes a man nearly all his time, after the material has started running out of the silos, to push it down so as to keep an even feed on the belt. Eventually the man has to get into the silo and use a shovel to clear the corners and sides. If the material sets into a stiff mass whilst in the silo, the harder it is to get it out. By reducing the size of the lime by grinding or passing it through a fine screen and by mixing with sand before hydrating, the stickiness is reduced and better bricks obtained, but the material always will stick to a certain extent. Generally speaking, the material should not stay in the silo more than forty-eight hours, and twenty-four hours is usually ample. If it remains longer it may harden slightly, but this will not be very serious. This is shown by an instance which came to the author's notice: Owing to an accident to the press one Friday afternoon the silos became full. It was necessary for the material to remain there until the Wednesday of the next week. It might be supposed that it would have been necessary to send a man into the silo with a pick, and perhaps dynamite to get it out; but such was not the case. He got in there with his hoe, and pushed it down on to the belt without any trouble at all!

Final Mixing. The material is drawn from the silos by some form of conveyor, a belt or worm being usually employed, so that the mixture of sand and lime is delivered at a constant rate, and quite automatically to the mixing mills. These should, in most cases, be of the edge-runner type, as this kind of mill effects a better "pasting" of the material. This rubbing action of the mill—which is a weakness

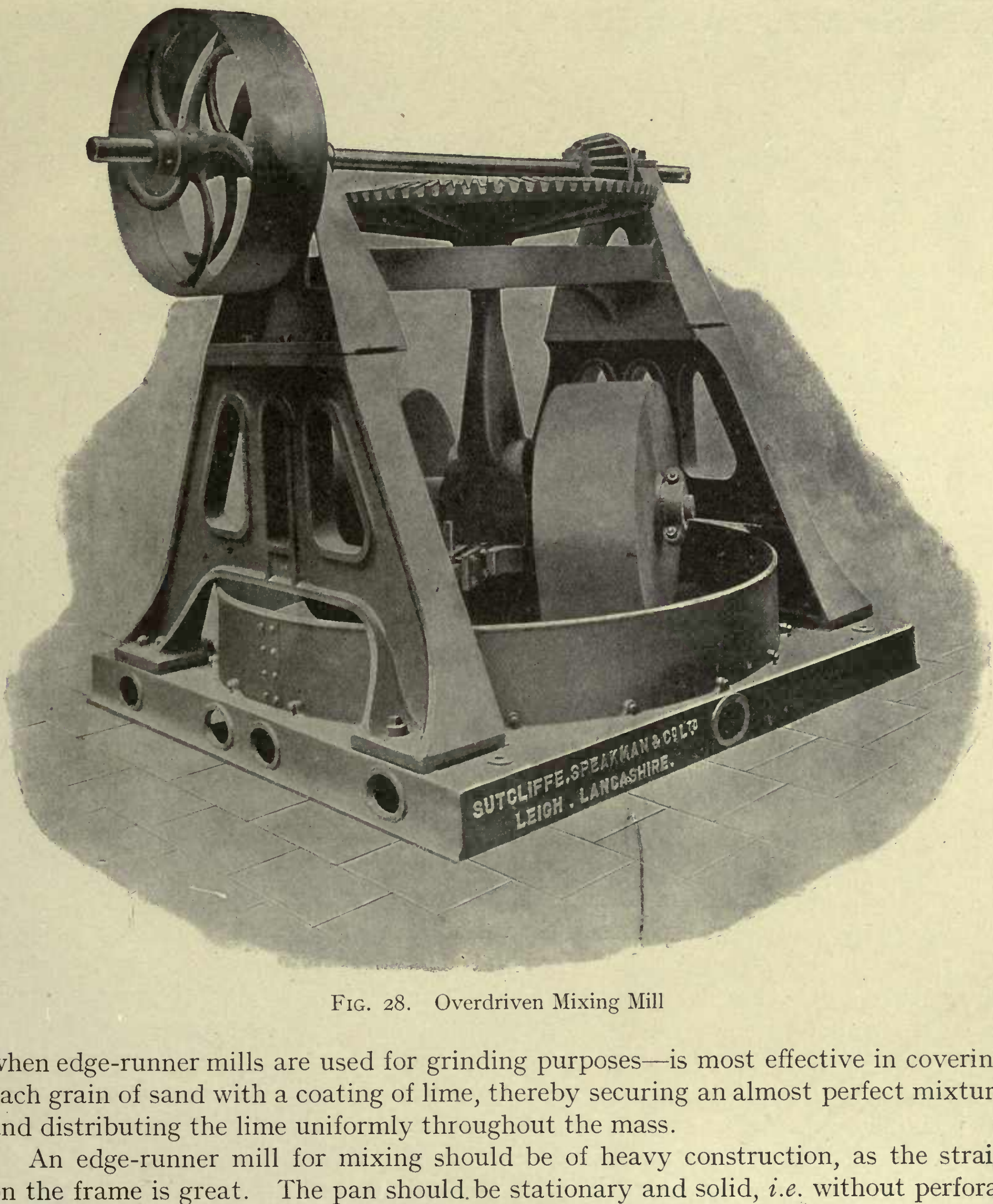


FIG. 28. Overdriven Mixing Mill

when edge-runner mills are used for grinding purposes—is most effective in covering each grain of sand with a coating of lime, thereby securing an almost perfect mixture and distributing the lime uniformly throughout the mass.

An edge-runner mill for mixing should be of heavy construction, as the strain on the frame is great. The pan should be stationary and solid, *i.e.* without perforations. The rollers or runners must be sufficiently heavy for their purpose as it is not economical to employ those which are too light. The runners should be made rather wider than is customary for crushing mills of this type and should be hooped round with steel tyres, so that wear and tear may readily be made good. It is sometimes considered an advantage to employ rolls which are slightly conical, but these are less effective in "rubbing" the paste. To ensure smooth working the bearings

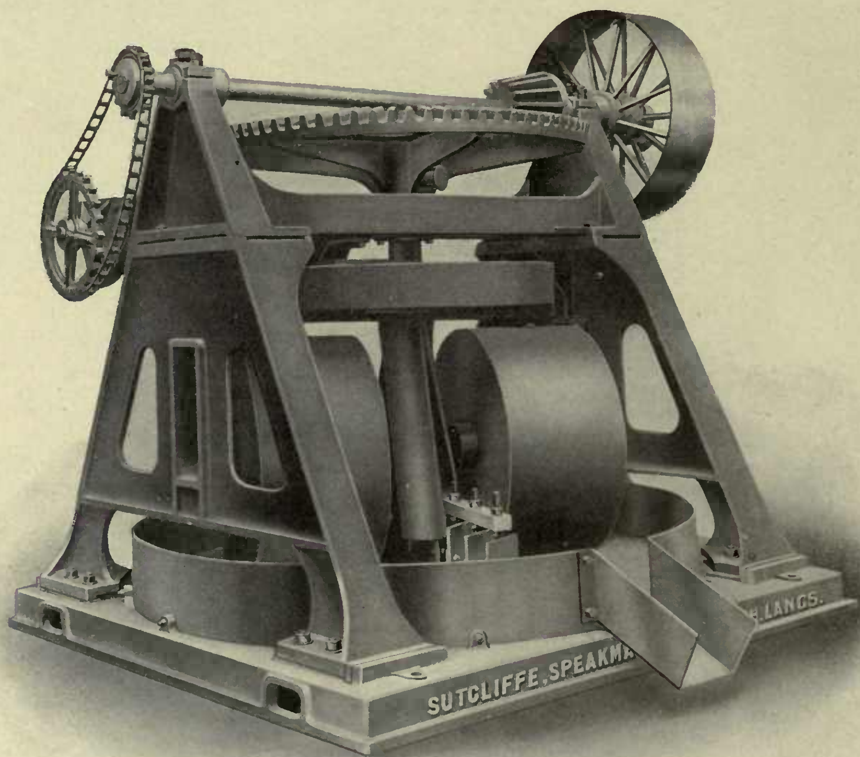


FIG. 29. Continuous Mixing Mill

must be kept in order and must be readily accessible. This is particularly necessary as regards the bearing at the base of the vertical driving shaft.

These mixing mills are often worked on the batch system, that is to say, a definite quantity of material from the silo is placed in the mill (Fig. 28) and after being treated therein for about twenty minutes, the charge is removed by means of a shovel or deflector. This method is slow and is the most effective, but self-emptying mills which work in a continuous manner are employed; they are less troublesome to use. It is, however, better to have two batch mills rather than one continuous one as far as the quality of the product is concerned. The mill shown in Fig. 29 is of this continuous type, the material being fed on to the plate just below the cross frame and then passes down the pipe to the centre of the pan. The treated material is, in each case, discharged in a steady stream from an opening in the side of the mill. In Fig. 30 the material is fed direct into the pan of the mill.

In order that the mixing may be still more effective a double deck mill (Fig. 31) may be employed. The upper part of this mill is an open pan in which the material is subjected to the action of ploughs or scrapers which turn it over repeatedly before passing it to the edge-runner mill below. The material is fed to the outer edge of the upper pan where it is stirred, mixed, and scraped towards the centre. It then falls through openings into the lower pan, where it is turned over by the multiple scrapers

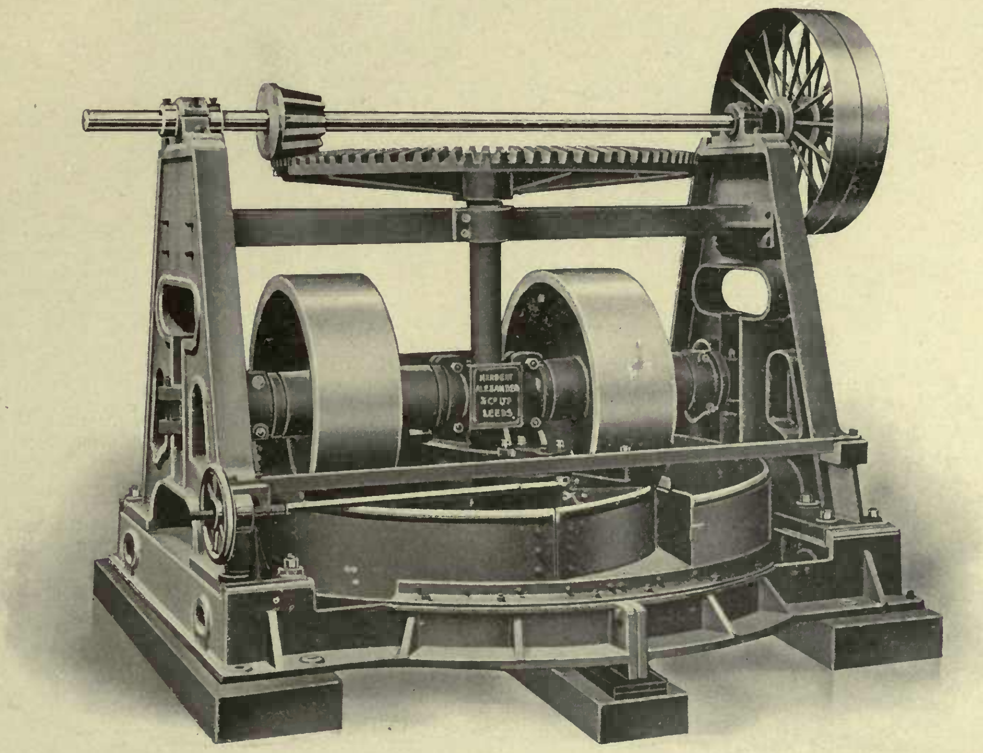


FIG. 30. Continuous Mixing Mill

and crushed by the edge-runners. In this way it becomes thoroughly mixed before it reaches the delivery outlet. The upper pan may be heated by steam if desired.

A trough mixer (Figs. 23 to 25) is sometimes sufficient for the final mixing and requires less power to drive it than is needed for a pan-mill, but the latter is always preferable because a trough mixer does not cover the grains of aggregate so thoroughly with the lime.

Whichever type of mixing mill is used it is essential that it shall be efficient. Ordinary mortar mills, whilst apparently very similar in construction, are seldom, if ever, suitable for use in lime-sand brickmaking. They do not mix the material with sufficient thoroughness, nor do they secure a sufficient "pasting" of the mixture. To avoid disappointment it is advisable to treat some of the material in a mill before actually purchasing the latter.

In use, the mixing mills should be placed above the presses, and should deliver direct to the presses. In some works these mixing mills are placed very disadvantageously. If they are placed below the bottom of the silos, so that the latter may feed directly into them, an elevator is necessary to lift the material to the presses. This is awkward as the material is difficult to move with elevators; also they require almost constant attention and the cleaning of them is expensive. The best position is for the final mixer to be intermediate between the bottom of the silo and the top of the presses so that no elevation of the material is required.

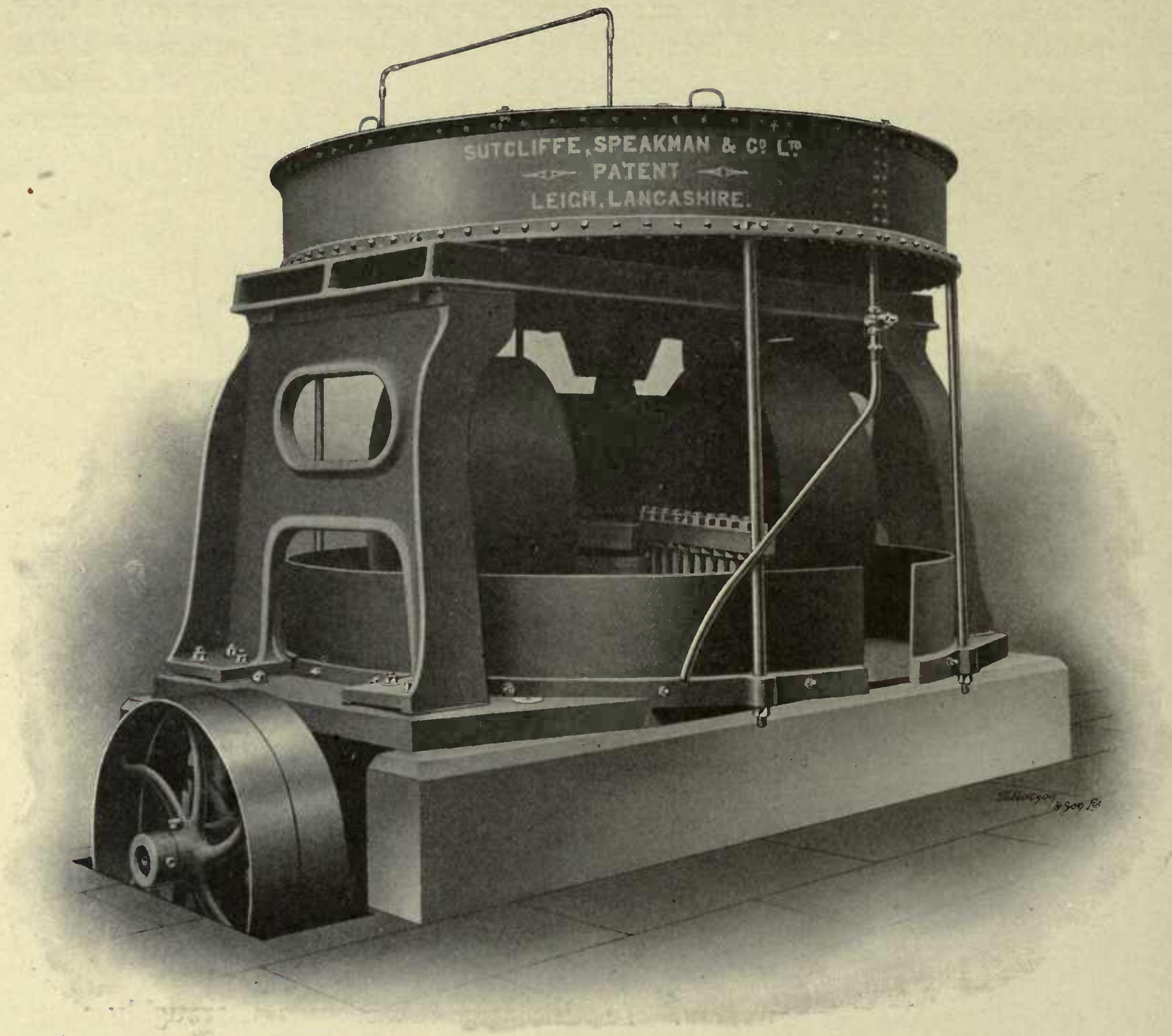


FIG. 31. Double Deck Mixing Mill

Arrangement of Plant. Fig. 32 shows a plant using a modification of Method B, which is particularly satisfactory where the lime used is slow slaking and where, consequently, large silos must be used. In this plant the sand brought to the machine-house in waggons is thrown into the hopper of the automatic feeder, E, which is of the type shown in Fig. 17. From this feeder the sand falls into an elevator, F, which raises it into the upper storey situated on top of the silos, H, and

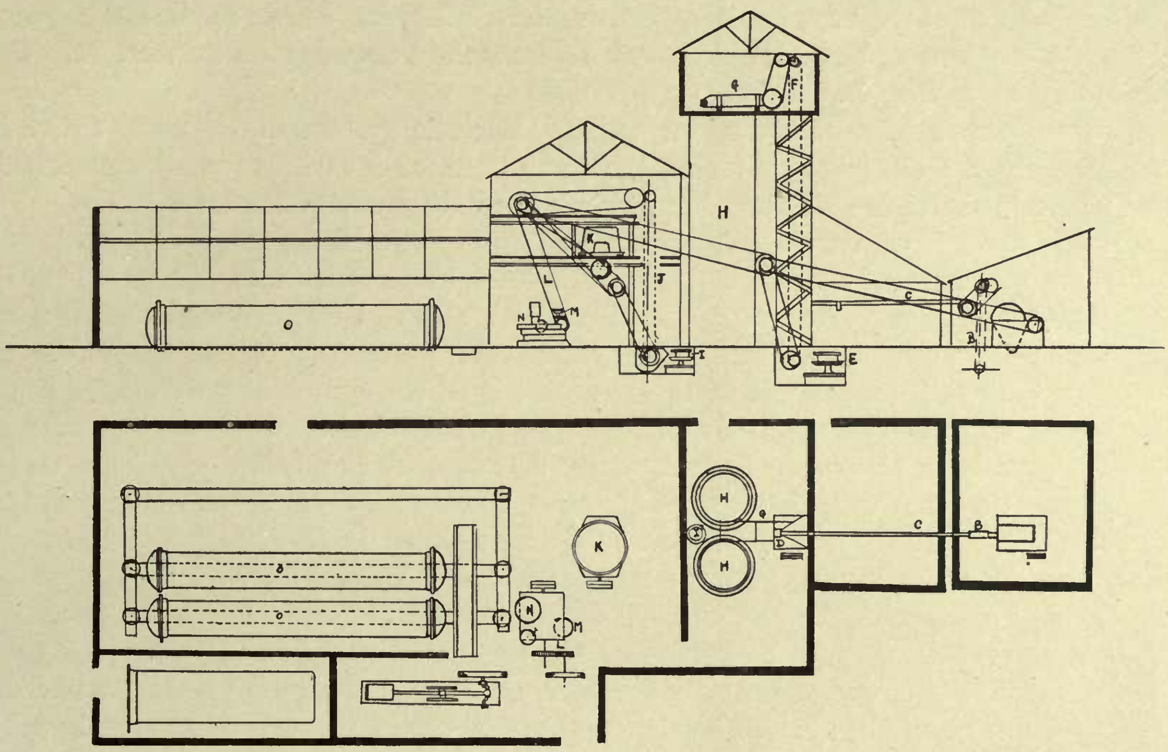


FIG. 32. Plant for Method B

discharges it into a double shafted differential mixer, G, similar to the one shown in Fig. 24.

The lime, in its fresh unslaked condition, is ground in a ball-mill, A, so as to pass through a sieve with 25 × 25 holes per square inch, and is raised by means of an elevator, B, to a screw conveyor, C, which in turn passes the lime into the hopper over the lime-feeder, D. This feeder is of exactly the same construction as the one used for feeding the sand, but is smaller. The lime coming from this feeder also passes into the same elevator, F, into which the sand falls, and is in the correct proportions required by the quantity of sand which is passed by the sand-feeder.

The sand and lime, in passing through the differential mixer, G, are thoroughly mixed, the 8 per cent. or so of water necessary to ensure the thorough slaking of the lime being added in the mixer.

This damp mixture of the sand and lime falls from the mixer into one or other of the silos, H, and by using two silos to each mixer, as shown, one silo can be receiving its charge of material whilst the other is being drawn upon to keep the plant in operation. At the base of these silos, and mid-way between the two, is situated an automatic feeder, I, similar to E. The work of this feeder is to regulate the discharge of the elevator, J, which raises the material and passes it into the upper pan of a double deck mill, K, similar to Fig. 31. This mill has two discharge openings in the base, so that it can feed the two hoppers, L, feeding the presses, N. At the base of these hoppers is an automatic feeder, M, which regulates the discharge to the presses, N. The bricks are then stacked on waggons and run into the hardening chambers, O.

Advantages and Drawbacks of Method B. The silo system as described above is undoubtedly the cheapest as far as the mere costs of manufacture are concerned, and where the sand used is very damp this is the only practicable method.

If the sand is of varying dampness this method is likely to give trouble, as occasions will arise where too little water is added and quicklime will then remain unhydrated. These particles of quicklime which have escaped combination with the water—because of an insufficient quantity of water—will cause the bricks to crack or "blow," on account of the weathering of the lumps of unhydrated lime, the bricks may swell so much that they cannot be taken out of the heater and will vary so greatly in size as to be practically useless. The addition of enough water to hydrate the lime will, if the sand is damp, cause trouble at a later stage, as the mixture will be too wet and will tend to unmix when in the silo, after which no amount of "mixing" will cause the materials to reunite.

Tests to ascertain the amount of water in the sand take too long to make, so that the material must be used "as it comes," with the result that it is only under favourable circumstances that this method can give uniformly good results. The difficulties could be avoided by drying the sand first, but this is far too costly to be practicable, and Method B is, therefore, only used for very damp sands or wet granulated slages to which no water need be added, or to very dry materials such as destructor-clinker, crushed slag and dry sand. The first two of these are, however, better treated by a process which will ensure the hydration of the lime they naturally contain, Method E being the most suitable.

Given sufficiently careful treatment, suitable materials and favourable conditions, this method is cheap and satisfactory, but, as will be seen from the foregoing remarks, it is not well suited to some natural sands on account of the risk of some lime remaining unattacked by the water owing to there being an insufficient quantity of this fluid.

Notwithstanding the foregoing criticisms, the fact remains that no firms known to the author find any serious difficulty in arranging their mixture satisfactorily so long as the manager exercises a reasonable amount of oversight, and Method B must, therefore, be regarded as satisfactory if properly worked.

Method BI is a simplification of Method B and consists in omitting the use of a silo and a second mixing of the materials.

This method of working requires a fresh, fat lime—a so-called fat plasterer's lime—as hydraulic or lean limes are slow in slaking. In the plant shown in Fig. 33 the lime is ground in a ball-mill, J, and collected in bags underneath the discharge of the machine. These bags of lime are then raised to the top floor by means of a

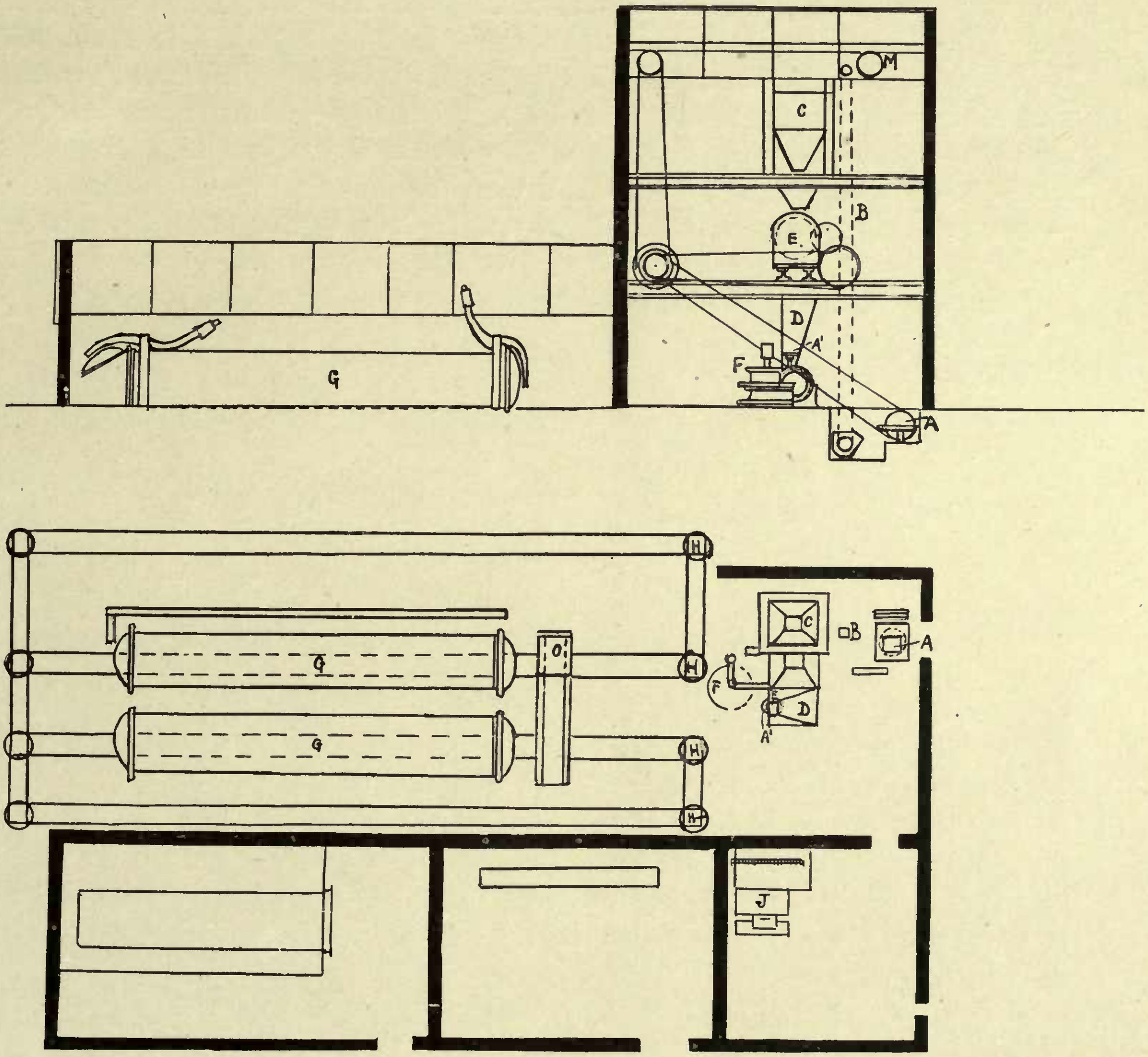


Fig. 33. Plant for Method BI

sack hoist, M. The sand is brought to the plant in waggons of about ¼ cubic yard capacity, which are discharged into the automatic feeder, A, which feeds the elevator, B, with a constant supply of material. The sand taken by the elevator is discharged into the main sand-hopper, C. The mixer on the upper floor has two hoppers—one for lime and one for sand—in which the attendant can measure a charge of sand and lime by filling each into its proper hopper to a certain height, and then discharging them into the mixer, E. The first charge taken from the hoppers may consist of 3000 lb. of sand and 500 lb. of lime. To this thirty to forty gallons of water must be added from a tank provided for this purpose.

This first mixing will immediately become hot, on account of the slaking of the quicklime, being also aided by heat retained by the mixer after it has been working for some time, and, if required, by steam injected into it ; in this way the whole of the lime is slaked. It should be observed that if the mixer is made sufficiently large it need not be sealed, in fact, it is better if the feed-hole is left open so that steam may blow out. During the mixing of the first charge—which requires about twenty minutes—the sand-hopper is filled again with sand, which is then dropped into the mixer. A further mixing of this sand with the first charge—for about ten minutes—completes the preparation of the material. During this time the man again fills the hoppers with sand and lime ready for the next preliminary charge. The man then discharges the contents of the mixer into the hopper, D, feeding the press, F, and begins to make a fresh mixing.

The operation results in :

Sand for first mixing . . .	3000 lb.
Sand for final mixing . . .	3000 ,,
Lime	500 ,,
	6500 ,,

or enough material for 1000 bricks with about $7\frac{1}{2}$ per cent. lime, which is the correct proportion in many works.

At the base of the hopper, D, is an automatic feeder, A1, which maintains a regular and automatic supply of material to the press, F, and is so arranged that when the press is stopped the feed stops simultaneously.

As the bricks come from the press they are stacked on two waggons in front of the press, two turntables, H, being provided, so that there are always two waggons in front of the press. These turntables must be good ones on running steel balls; the turntables often seen require too much labour. A suitable turntable when fully loaded with bricks can be turned round with the pressure of the foot.

When the waggons are filled they are run on a transfer car, O, into the hardening chamber, G, where they are steamed for eight to ten hours, after which the bricks are drawn from the hardening chambers and are ready for immediate use.

METHOD C. This is really a modification of Method B, and is intended to reduce the cost of manufacture and improve the mixing. In this method the whole of the lime is mixed with about one-fourth of the sand or other aggregate, and these materials are then wetted and mixed in a trough-mixer as described on p. 51 and the mixture is delivered to a silo as before. The product from the silo is placed in an edge-runner mill, together with the remaining three-quarters of the aggregate and is treated as described on pp. 53 to 62. The plant is shown in Fig. 32.

This method is better than Method B inasmuch as the lime is more uniformly mixed with the material. By using a smaller quantity of sand or other aggregate in the first mixing there is less chance of the lime segregating, and a more thorough mixing can be given because a much smaller quantity of material has to be treated.

Special care is needed to ensure sufficient water being present to hydrate the whole of the lime without the excess of water making the paste too soft. The fact that only one fourth of the aggregate is used, naturally prevents a large excess of water being added, as it would obviously make the mixture far too sloppy. Any excess of water present is usually taken by the remaining aggregate without any harm being done. It is only where very wet sands are used that this method is unsuitable.

This method has the disadvantage that the material in the first mixer and in the silo is much more adhesive than when the whole of the sand is added, but this is compensated by the smaller quantity to be treated and the greater ease with which any adherent portions can be pushed off the walls of the silo by a man with a suitable long-handled spade. Hence it is often preferred to Methods A or B.

METHOD D. The essential feature of this method is the *grinding* of the lime and part of the aggregate to an impalpably fine powder. This ensures a much better distribution of the lime, more perfect hydration, and enables the reaction between the lime and water to take place more completely.

There can be no doubt that the mixing of the dry quicklime with dry aggregate by grinding both to the greatest practicable fineness in a tube-mill is the best means of securing a perfect mixture and, of all silo methods, D is, therefore, the best. It is indeed questionable whether, for lime-sand bricks and for aggregates which contain no free lime, there is any other method which is superior to it unless it involves the same essential feature, namely, the mixing of the superfinely ground lime with some of the equally fine aggregate.

It has previously been pointed out that a certain proportion of sand or aggregate in the form of an impalpable powder is necessary in order that the lime may combine with it. The addition of sand to the lime thus forms a convenient means of producing this extremely fine sand, which is afterwards mixed with the remainder and the whole mixture placed in the silo.

Method D is really a modification of Method B, and may be briefly described as follows : The lumps of quicklime, together with about one-quarter of the sand or aggregate, are placed in a tube-mill and ground to flour, as described on pp. 31 to 33.

This flour may be (*a*) treated with water in a trough mixer, this wet mixture then being placed in a silo and the remainder of the aggregate being added to it in an edge-runner mill as described in method C (p. 64) or (*b*) the flour and the remainder of the aggregate may be passed through a trough-mixer and into a silo, exactly as in Method A (p. 45). Treatment (*a*) is generally better than (*b*), for reasons given in the description of Method B.

In either case the mixture must be thoroughly well mixed in a differential mixer

(p. 52) or panned in an edge-runner mill as described on p. 57, as it is only possible to make good bricks when the distribution of the lime is very uniform and each grain of aggregate is properly coated with hydrated lime.

Method D is used in the plant shown in Fig. 34. In this case the lime is fed to a ball-mill, A, and ground to a mesh of 25 × 25 per square inch. It is then raised by means of a lime elevator, B, into the lime-hopper, C. This hopper feeds one barrel of the measuring machine, D, and the other barrel is fed with sand from the sand store. The machine D measures the sand and lime in the proportions required for the preliminary mixture and delivers them to an elevator, E, which

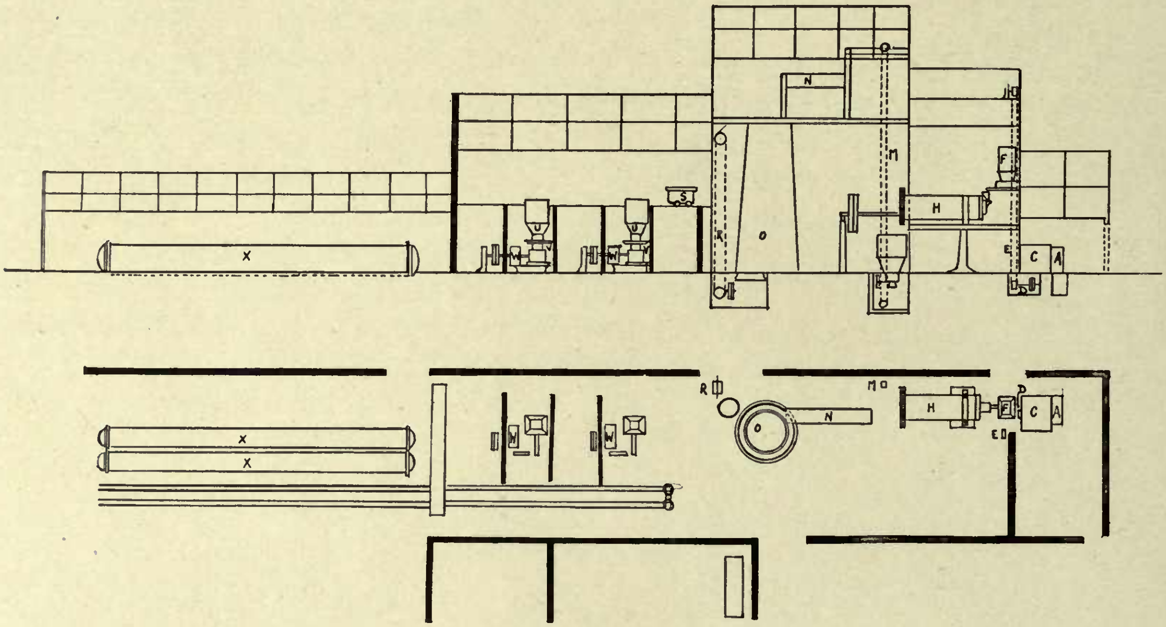


FIG. 34. Plant for Method D

raises it to the preliminary mixer hopper, F, which is situated over and feeds the tube-mill, H, in which the preliminary mixture is reduced to the fineness of cement.

The ground mixture from the tube-mill is elevated by M, and fed, along with the sand, by means of an automatic feeder, to a 10 ft. differential mixer, N, where the ground preliminary mixture and the bulk of the sand are thoroughly mixed and incorporated with the required amount of water and then deposited in the silos, O, where the mixture is allowed to stand for some time in order to ensure the complete hydration of the lime.

An elevator, R, takes the material from the silos and delivers it into waggons, S, for charging the auto-feeders, U. From this feeder the material is passed through a differential mixer, V, for its final mixing. Thence it passes to the presses, W, to be made into bricks.

As the bricks are delivered from the presses they are stacked on waggons and run into the hardening chambers, X, and after eight hours steaming are ready for use.

In a large plant the various hardening chambers may be connected together in such a manner that the exhaust steam from one chamber can be turned into the next chamber about to commence steaming, thus greatly reducing the steam consumption.

Advantages. This process involves the silo-ing of the whole mixture, including a proportion previously ground fine in the tube-mill. In this way the ground product forms a matrix in which the remaining bulk of the sand is bonded, thus giving the bricks a high strength and low porosity, and also reducing the wear and tear on the lining of the press.

METHOD E consists essentially in making a mixture of sand and lime and treating it in a hydrating cylinder with water or with water and steam. Various modifications of this method are in use ; thus some manufacturers have found that the hydrating drum acts much more satisfactorily if the lime is ground before being put into it or if the material discharged from the drum is ground in a tube-mill, as in Method D (p. 65). If the lime is reasonably pure, either method is satisfactory, but an inferior lime—if it is used at all—should be hydrated separately (Method A) screened, and the particles passing through the screen may then be ground in a tube-mill, if this is thought necessary, or the particles which are too coarse to pass through the screen may be re-hydrated (if possible) or rejected, as they often contain the bulk of the impurities.

If large cylinders are used—those holding about seven tons being satisfactory—this process is technically very valuable and efficient, but it is also costly. The cost may be reduced by mixing the lime with only one quarter of the sand or aggregate, the remainder being mixed with the hydrated material in a trough mixer or pan-mill. If preferred, the cylinder may be opened after finishing the hydration, the remainder of the aggregate delivered into it and the cylinder revolved for another twenty minutes, or until the mixing is complete. This obviates the use of a trough mixer, but requires more power. Moreover, the trough mixer may be used as a conveyor to take the mixture to the presses. It is very desirable that the material should be placed in a silo for eighteen to twenty-four hours in order that all balling * of the mixture entering the pan may be prevented. Otherwise, the hydrating cylinder must be large enough to deal with a day's supply at a time.

Fig. 35 shows a plant using *Method E* in which the lime is ground in a ball-mill, A, and both it and the sand are supplied in correct proportions by means of the automatic feeders, B and C, which discharge into an elevator, D. The elevator discharges its contents into a steam-heated mixer, E (*see* Fig. 36), from which it passes to the silo, F, where it is stored until all the lime is hydrated. The automatic discharger, G, at the base of the silo, F, conveys the material to another elevator, H, which raises and discharges it into the 9 ft. differential mixer, J, for the final mixing. Thence it passes to the press, K, where it is made into bricks.

* This balling is due to a little steam condensing and forming localities where there is an excess of water. In the silo this water is either evaporated or distributed so uniformly that the contents of the silo are quite " dry " within a few hours.

The bricks are stacked on the waggon, L, and taken on the transfer car, M, to the hardening chamber, O. After treatment in the latter, the bricks are withdrawn ready for use.

Method EI differs from Method E inasmuch as the lime and some of the aggregate are ground together previous to hydration. This method only differs from D in

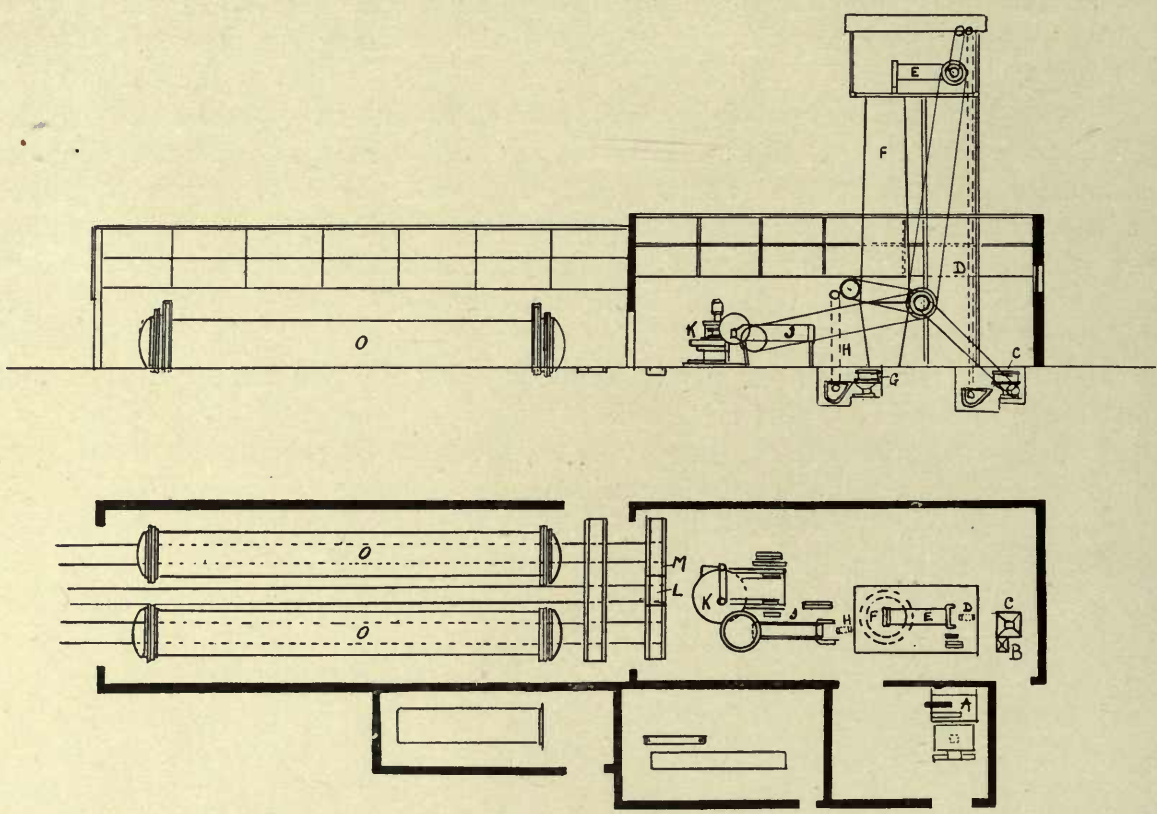


FIG. 35. Plant for Method E

the use of a steam-heated hydrating drum, so that bricks made by it have the general characteristics of those made by Method D.

Method EII. In another modification both the aggregate and the lime may be hydrated separately, as in the arrangement for a brickmaking plant for clinker shown in Fig. 37, the operation of which is as follows :

The lime, which must be a fresh, fat lime, is broken in a lime breaker, V, to a suitable degree of fineness and is passed to a lime-slaker, W, by means of an elevator. A conveyer, Y, then takes the slaked lime to the hoppers, J, from which it passes into an automatic feeder, K, to a 6 ft. differential mixer, M.

The clinker is crushed in a grinding mill, A, and is carried by an elevator, B, to an automatic slaker, C, from which it goes to a magnetic separator, D, where any pieces of metallic iron are eliminated, the clinker travelling to the screen E, in order to take out any pieces which are too large, and falling into the hopper F.

The screened clinker then passes to the hydrator, G, where all the lime contained in it is slaked. This, as already explained, is most important in the making

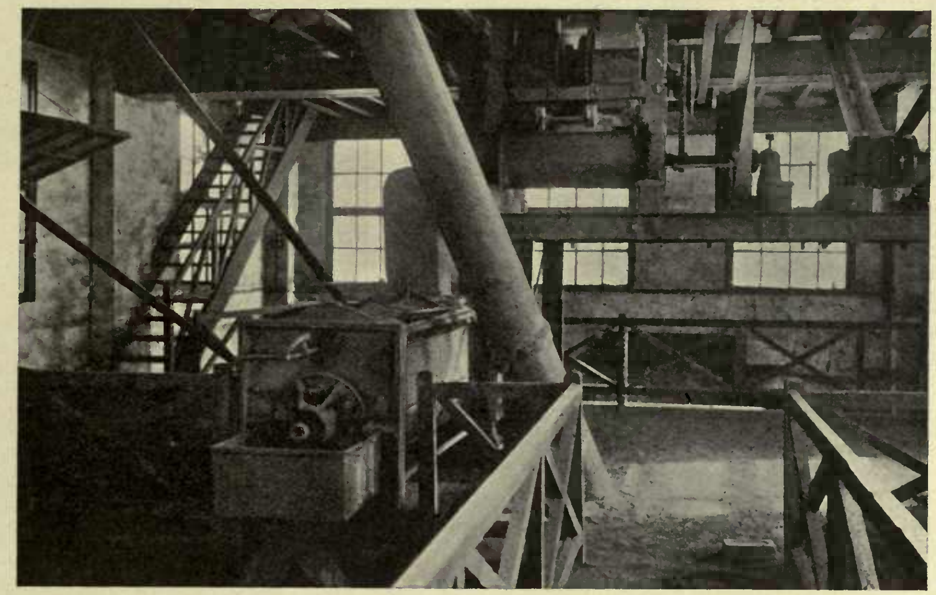


FIG. 36. Steam-heated Mixer

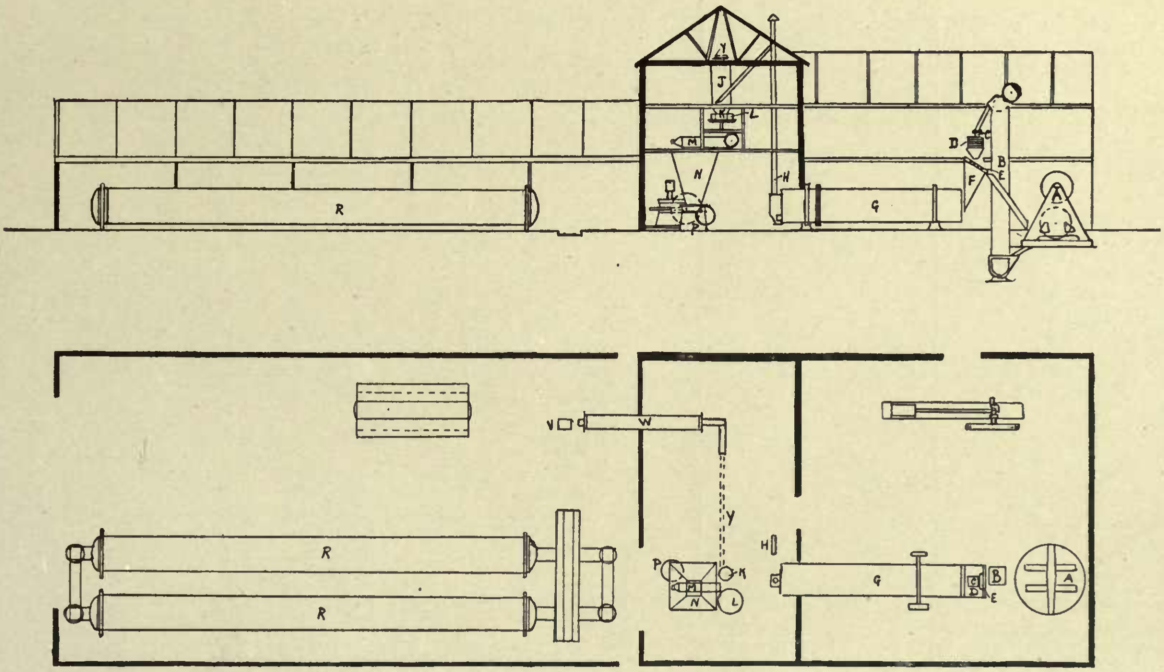


FIG. 37. Plant for Clinker Brickmaking

of bricks, without this treatment the bricks would burst in the chambers on account of the action of the steam. The hydrator, G, empties the hot clinker into an elevator, H, which passes it into an automatic feeder, L, which regulates its passage to a differential mixer, M. In this mixer the clinker is mixed with the slaked lime and moistened, the mixture then falling into the hopper, N, leading to the press, P. The

Operations Arranged in Order of Methods

Method A	Method B	Method C	Method D	Method E
Raw Materials: *i.* Graded aggregate *ii.* Lime putty or hydrated lime *	*i.* Graded aggregate *ii.* Ground quicklime *iii.* Water	*i.* Graded aggregate *ii.* Ground quicklime *iii.* Water	*i.* Graded aggregate *ii.* Lump lime	*i.* Graded aggregate *ii.* Ground lime *iii.* Water
Method: *a.* Measure out	*a.* Measure out all above	*a.* Measure out all lime, one-quarter aggregate and sufficient water for lime	*a.* Measure out all lime and one-quarter of aggregate	*a.* Measure out all lime, one-quarter aggregate and water
b. Mix in edge-runner mill	*b.* Mix all in trough-mixer or batch-mixer	*b.* Mix all in trough-mixer	*b.* Grind to dust in tube mill	*b.* Mix and hydrate in steam hydrator
c. Take to press	*c.* Store all in silo	*c.* Store mixture in silo	*c.* Mix with water in trough-mixer	*c.* Store in silo
	d. Re-mix in edge-runner mill (add more water if required)	*d.* Add remainder of aggregate and water to make correct consistency	*d.* Add remainder of aggregate and water to make correct consistency	*d.* Add remainder of aggregate
	e. Take to press	*e.* Mix in edge-runner mill or differential mixer	*e.* Store mixture in silo	*e.* Mix in edge-runner mill or differential mixer
* Made by putting quicklime in a mechanical hydrator and heating it with water, with or without steam	—	*f.* Take to press	*f.* Mix in edge-runner mill or differential mixer	*f.* Take to press
			g. Take to press	
	Method BI			Method EI
	aa. Measuring *ba.* Mix in batch mixer *ca.* Take to press			*aa.* Grind lime with one-quarter of aggregate to dust in tube mill *ba.* Hydrate dust in steam-heated drum *ca.* Store in silo *da.* Add remainder of aggregate (water if required) *ea.* Mix in edge-runner mill *fa.* Take to press
				Method EII (*see* p. 68)

prepared material is then converted into bricks in the press, P, the bricks being placed on waggons and run into the hardening chambers, R, where they are subjected to the action of steam under pressure for ten hours. On leaving the chambers the bricks are ready for use.

Another modification of Method E consists in using a batch-mixer which is heated by steam, and is specially suitable for some kinds of granulated slag.* The mixer holds enough for 1200 bricks, or the equivalent of half an hour's work of the press. It is charged with the whole of the lime and one quarter of the slag, and is worked in a manner very similar to a hydrating cylinder, except that as the batch-mixer is open there is no great development of steam-pressure. After a run of about twenty minutes the remaining three-quarters of the slag is added and the mixing continued for another ten minutes; then the mixture is discharged ready for the press. It is obvious that this process does not secure so complete a hydration of the lime in difficult cases as when steam is used under pressure, but with many granulated slags it works so efficiently and is so cheap as to prove perfectly satisfactory.

The quality of the bricks is improved if the lime is ground with a quarter of the slag in a tube-mill as described in Methods D and EI.

The Table on page 70 summarises the various operations used in preparing and mixing the materials:

The following Table shows what are usually the best methods for any given aggregate. Where, on account of cost or for other reasons, the "best" method for any given material cannot be used, one of those mentioned in brackets should be tried. It must be clearly understood, however, that variations in the nature of a material may necessitate the use of a combination of two or more methods, or may permit the omission of some process.

BEST METHODS

In each instance the material is understood to be in the form of a suitably graded powder; rocky or lumpy material must be reduced to this state.

Crushed rock †	D or EI (A, B, BI, C, E)
Sand	D or EI (A, B, BI, C, E)
Destructor clinker †	E or EII ‡
Granulated slag *	D or EII (E, BI)
Dry slag *†	D or EII (E, BI)

* Some slags contain sufficient free lime, so that no more need be added providing that the slag is ground sufficiently fine in a ball-mill. Bricks made of some slags also contain so much cementitious material that they harden sufficiently on exposure to air and do not need an autoclave.

† Requires to be ground before use.

‡ It is essential that the lime and powdered clinker should be heated with steam under pressure during slaking. Some clinkers require heating for several hours before they are properly slaked, and no clinkers slake at all readily. As failure to slake all the lime renders the production of good bricks impossible, the importance of ensuring complete hydration is obvious.

* With sound and good lime the use of steam is unnecessary, as the heat developed is sufficiently great without it.

CHAPTER VI

PRESSING THE BRICKS

For pressing the prepared material into bricks, the press used must be strong and powerful, as the bricks require a pressure of *at least* two tons per square inch, or a load of eighty tons on each brick. One hundred tons is preferable, and a pressure of 100 to 150 tons per brick is employed in the best presses. The pressure must be applied slowly so as to press out the air, and the bricks should be pressed equally on top and bottom.

In the early days of the manufacture of lime-sand bricks the presses used were of the simple "fly" pattern used for ordinary bricks and for punching out metals. These were found to be lacking in strength, and special presses have, therefore, been designed for this special kind of work. The most effective modern presses used are of the "revolving table" type, as shown in Figs. 38 to 42.

The earlier types, which only gave a top pressure, failed to produce a sound brick, and owing to the weaknesses in their design they soon proved inefficient. They are so seldom used for lime-sand bricks at the present time as to make any further description of them unnecessary.

Among these earlier machines are the gravity-fed presses which are designed to fill several moulds at a time. Uniformity of filling is impossible under such conditions, and such machines are therefore unsuitable for the manufacture of sand-lime bricks.

The "Hercules" press shown in Figs. 21 and 38 was invented by Herbert Alexander in 1895. It is the pioneer among British presses and is the basis of nearly all the modern presses employed for lime-sand bricks. It is made in six sizes, with a capacity ranging from 500 to 4800 bricks per hour, and can be arranged to press either one, two, or four bricks at one stroke.

The more recent patterns of the "Hercules" press do not rely on gravitation to fill the moulds, but by a special arrangement of stirrers or scrapers working inside the feeding-pan, each mould in the revolving mould-table is filled with the exact quantity desired. Each mould is thus filled by a positive mechanical motion so as to ensure perfect uniformity in the size of the brick. The mould-table revolves intermittently, and at each movement a brick is automatically moulded, pressed, and delivered ready to be removed by the attendant. The bricks are delivered to the surface of the mould-table. They are not pushed off, and thus damaged in their green state, as is the case with some presses. The attendant can remove each brick exactly as it comes from the mould, perfect in shape and with clean, sharp edges, thus producing a first-class facing brick.

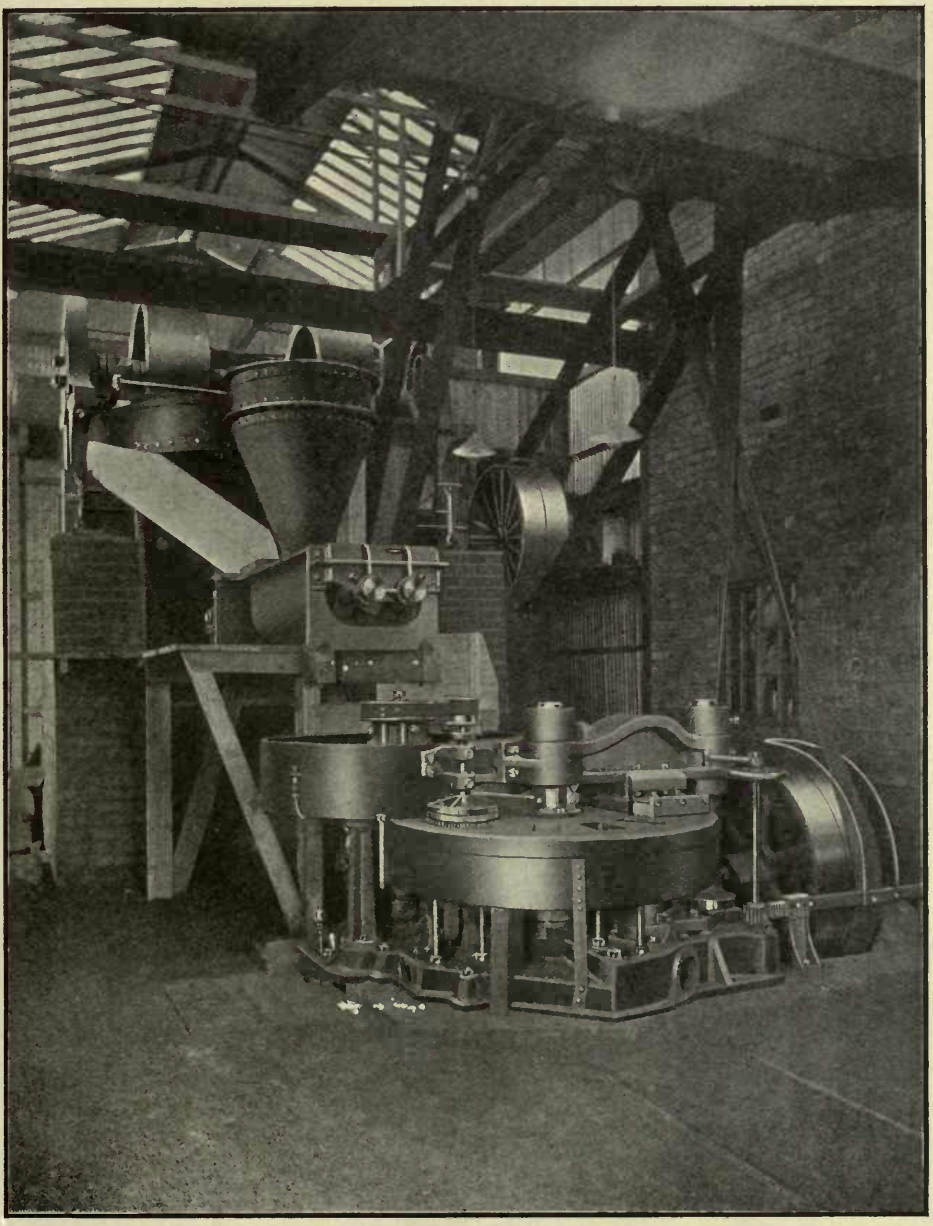


FIG. 38. "Hercules" Press
Courtesy of H. Alexander & Co. Ltd.

A hydraulic relief motion may be provided to prevent overpressure and consequent breakage, and the actual pressure exerted on each brick may be indicated by a gauge.

Each brick is moulded and pressed separately (unless otherwise specially arranged), thus ensuring perfect uniformity.

The number of moulds in the rotating table is arranged to suit the required capacity. Each mould is fitted with hard steel liners, which are reversible on both sides, thus giving four wearing surfaces. This device is of vital importance, as the cost of wear and tear is thereby reduced 75 per cent.

In an improved form of "Hercules" press the pressure is applied simultaneously

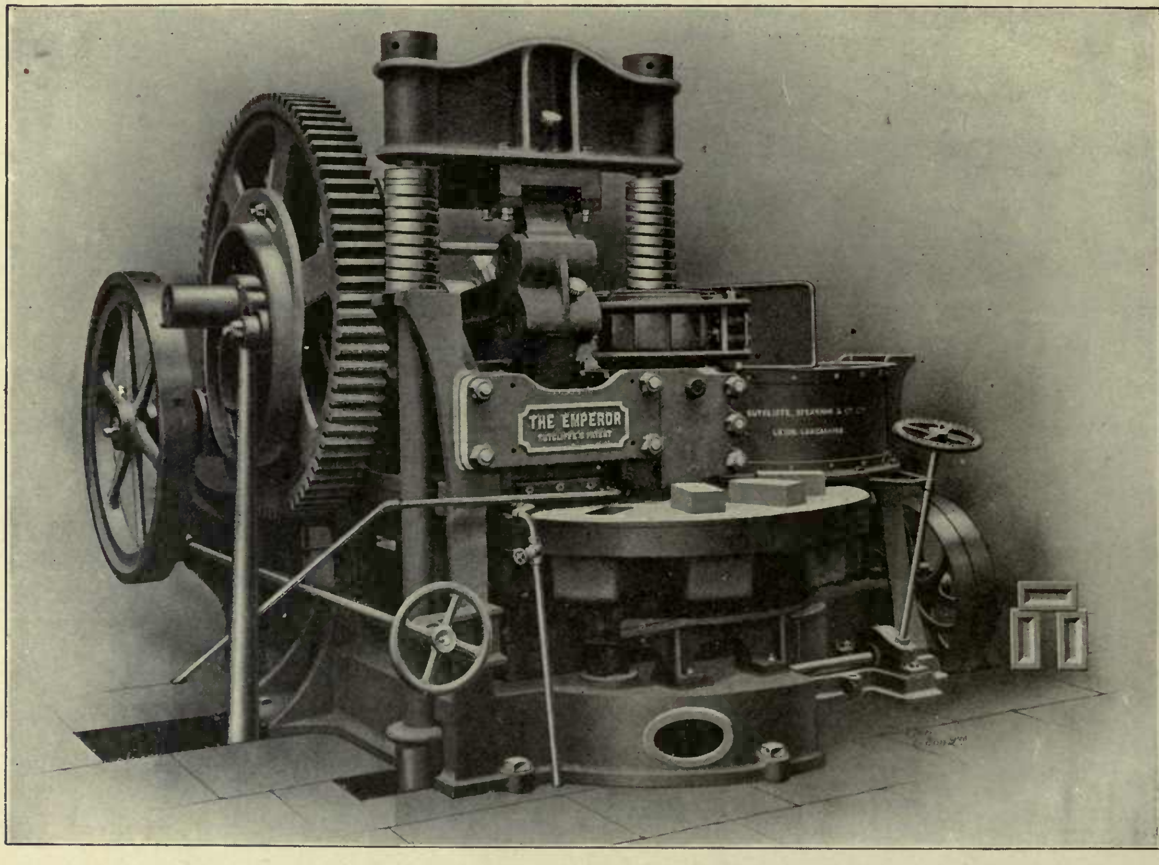


FIG. 39. Single "Emperor" Press

and positively on the top and bottom of each brick, by patent combined hydraulic and double beam movements.

The No. 0 size "Hercules" has a rated output of 1000 to 1200 bricks per hour.

The No. 1 size "Hercules" has a rated output of 1500 to 1800 bricks per hour.

The No. 3 size "Hercules" has a rated output of 2000 to 2400 bricks per hour.

The No. 4 size "Hercules" (with double compression) has a rated output of 4000 to 4600 bricks per hour.

The No. 4 machine must press three bricks at a time to produce its full output. When only one brick is pressed at once—which is always preferable so far as the quality of the bricks is concerned—the output is only 1300 to 1500 bricks per hour.

The power required by the "Hercules" presses varies from 6 to 30 h.p. according to the output.

In the "Emperor" press (Figs. 39 and 40)—which may be regarded as typical

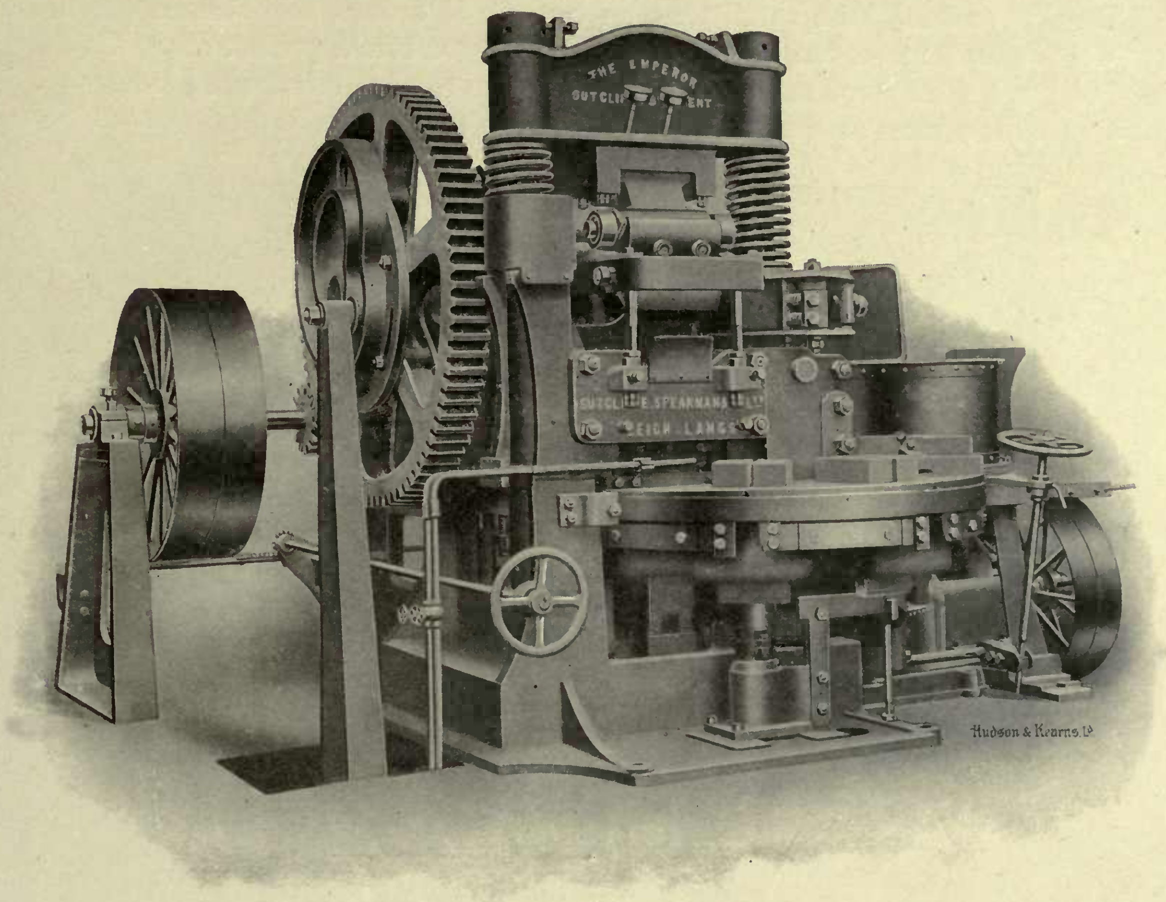


FIG. 40. Duplex "Emperor" Press

of the best machines for this purpose—eight or ten moulds are formed in a horizontal table, which is rotated one mould at a time in such a manner that, whilst one mould is being filled, there is another under pressure, and from a third the pressed brick is being discharged. The pressing mechanism is of the toggle and knee type, the greater part of the strains being taken by massive steel bolts, and by means of a patent "Expression attachment" two pressings are given to each brick, the first one squeezing the material to the edges and corners of the mould and the second one giving the final pressure to the brick. The first pressure is given by a specially shaped plunger, which secures the complete filling of every part of the mould at an approximately regular density. The pressure can be regulated by means of a hand-wheel, which controls the amount of mixture fed into the press. The power varies from 5 to 12 h.p. according to the material and output. In this press all working parts are in sight above the level of the table. The "Emperor" press is made by Sutcliffe, Speakman and Co. Ltd. in three sizes:

The No. 0 size "Emperor" has an output of 800 to 1000 bricks per hour.
The Single Emperor has an output of 1000 to 1500 bricks per hour.
The Duplex Emperor having an output of 1600 to 2600 bricks per hour.

Hydraulic presses are less suitable as they are too slow in action.

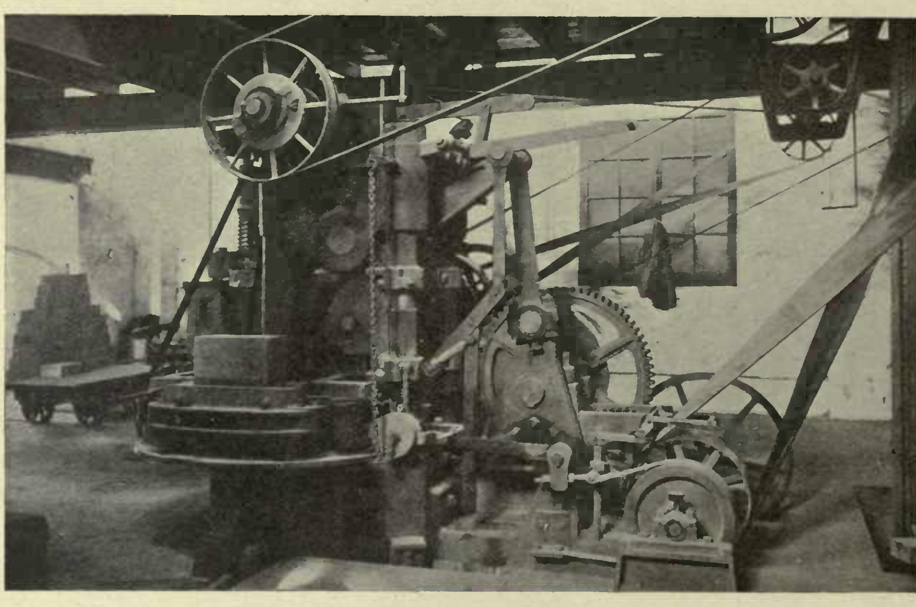


FIG. 41. "Emperor" Press used by Havre Municipality
Courtesy of Sutcliffe, Speakman & Co. Ltd.

In any press for lime-sand bricks there are certain obvious requirements. The most important of these are strength and durability. Some presses are pretty in design, but they are much too lightly built to stand rough usage, and after a year's wear they become noisy and subject to rapid wear and tear. A machine of greater solidity and strength may require rather more power to drive it, but this is more than counterbalanced by the saving in repairs.

In addition to ample strength, it is highly important to have ample means of ensuring relief in case of excessive pressure. It is sometimes argued that in a properly designed press the belt will slip if the press is overloaded, but, in a machine where the risks of careless usage are great, a more positive relief is often an advantage. Various systems of "breaking pins" give some security in this respect, but the best provision of all is a hydraulic cylinder relief. This should be fitted with an indicator so that the man in charge of the press may see what pressure is used in each case. With such a safety appliance the important parts of the press cannot be broken, nor can any substitute be applied unbeknown to the owner, as is so easily accomplished when breaking pins are employed. Further, the working parts should, as far as possible, be above the level of the table, so as to reduce or prevent material from the latter falling into the bearings. Adjustments should be provided for taking up wear and tear. The whole machine must be so well balanced that it works smoothly and without loss of power. The pressure should be regulated to suit the particular material used, and the bricks should be delivered on to the table ready for an attendant to remove them. They should never be pushed off the moulds, as this damages them considerably.

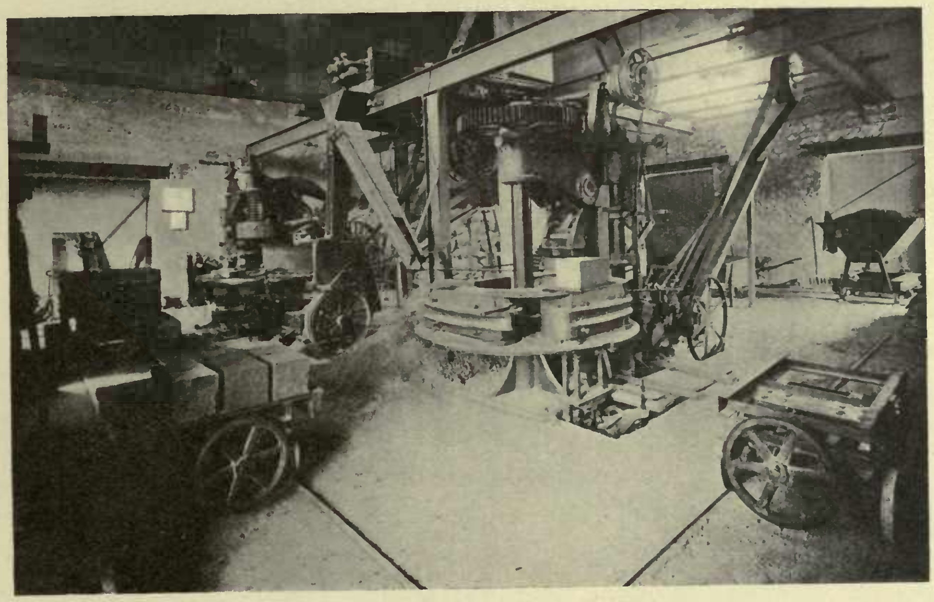


FIG. 42. Interior of Works making Slag Bricks and Blocks

Courtesy of Sutcliffe, Speakman and Co. Ltd.

The feeding mechanism attached to the press is of great importance, as lime-sand mixtures do not feed evenly into the moulds unless some special arrangement is provided for this purpose. The amount of material supplied to a mould should be supplied automatically, but capable of regulation whilst the machine is in motion, as it is troublesome to have to stop the machine to do this. Some arrangement should exist in this mechanism whereby the material is kept stirred to prevent choking, and to ensure that the amount of material supplied to the moulds is constant unless altered by moving a regulator. In other words, the feed should be as automatic as possible.

The moulds should be kept in a perfect condition, as variations in them will produce irregularly sized bricks, and consequently imperfect joints. It is a great advantage if special arrangements are provided whereby the lining of the moulds can be rapidly taken out and replaced by fresh ones, as much time is otherwise lost in this operation. It is no use attempting to work with a mould the lining of which is worn. This only produces bricks of irregular size which do not lay well and often cause trouble to maker and user alike.

Although presses are made which produce two bricks at once, it is usually wiser to instal two separate presses than one duplex one. The cost of the two presses is greater than of a duplex press with the same nominal output, but the better quality of the bricks produced in the former machines is well worth the extra initial cost. Moreover, in actual working, the author has found that two single

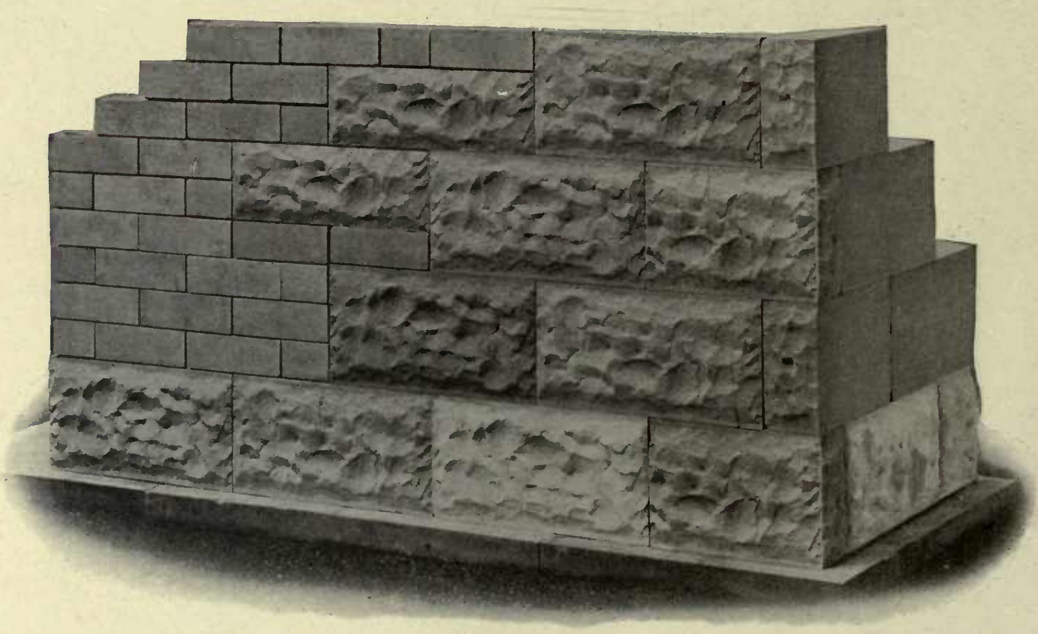


FIG. 43. Blocks of Artificial Stone made by "Emperor" Press
Courtesy of Sutcliffe, Speakman & Co. Ltd.

presses require less repairs than a duplex, and that such repairs as are necessary do not disturb the work so much. In addition to this, the power to suspend the use of one press is invaluable during slack trade.

Competition has resulted in a tendency to build presses of higher outputs than those mentioned, but this is a serious disadvantage to the user who gains a higher daily output only at the expense of more numerous and more serious breakdowns. The result is that the output over a number of years is not increased, but is often less than it would have been with machines run at the rates previously mentioned. It is doubtful whether any machine making one brick at a time should have a greater output than 1500 per hour, and in most cases 1000 to 1250 is a much safer average rate at which to work.

To prevent any misunderstanding it may be stated that a press which is suitable for lime-sand bricks is equally suitable for clinker or slag bricks (Fig. 42). The methods of preparation of the different materials should result in a mixture of almost identical characteristics in each case by the time it reaches the press.

Blocks and *slabs* are made in precisely the same manner as bricks, but owing to their larger size a modification in the press is necessary.

Paving Slabs and Bricks can be made by the use of sufficient lime (usually 15

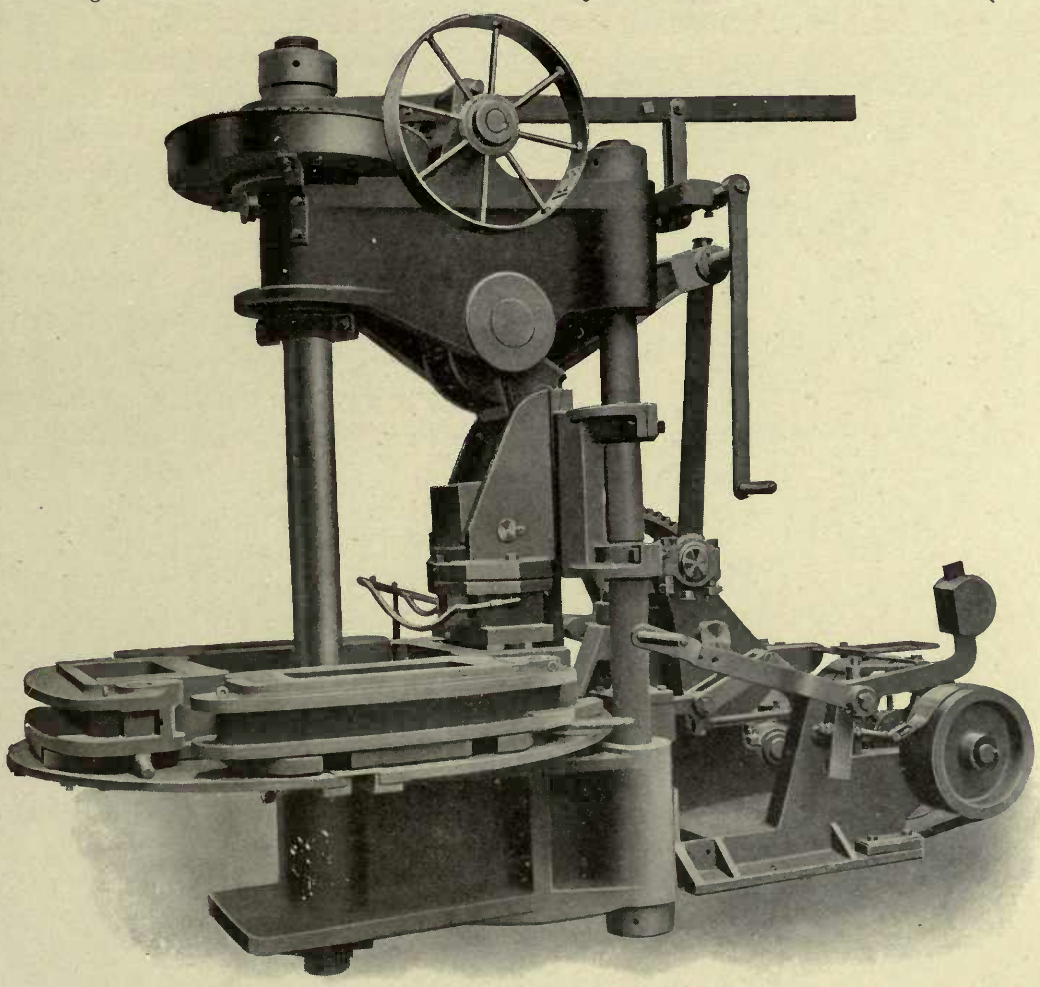


FIG. 44. Press for Large Blocks
Courtesy of Sutcliffe, Speakman & Co. Ltd.

to 20 per cent.), which are so dense that they have a porosity of less than 2 per cent. (by weight) and an ultimate crushing strength of 500 to 600 tons per square foot.

The arrangement of the plant used in one works for making paving slabs or *flags* is shown in Fig. 21.

The manufacture of such slabs and bricks requires special care, and a modified form of press must be used if good results are to be obtained. It is therefore necessary to consult an expert before attempting to make these articles (see *Preface*).

Linings may be fitted to the moulds so as to produce imitations of cut and dressed stone, as shown in Fig. 43, as well as various fancy moulded stones may be made in the same manner. If sand is used for the aggregate, such blocks have all the characteristics of a hard natural sandstone, but they can be made much more cheaply than by carving or dressing natural, quarried stone.

If clinker is used as the aggregate it is advisable to arrange the mould so as to give a facing of sand and Portland cement, as this has a closer resemblance to dressed stone than when clinker alone is used. The facing is applied by first using the facing material and filling the remaining portion of the mould with the clinker mixture.

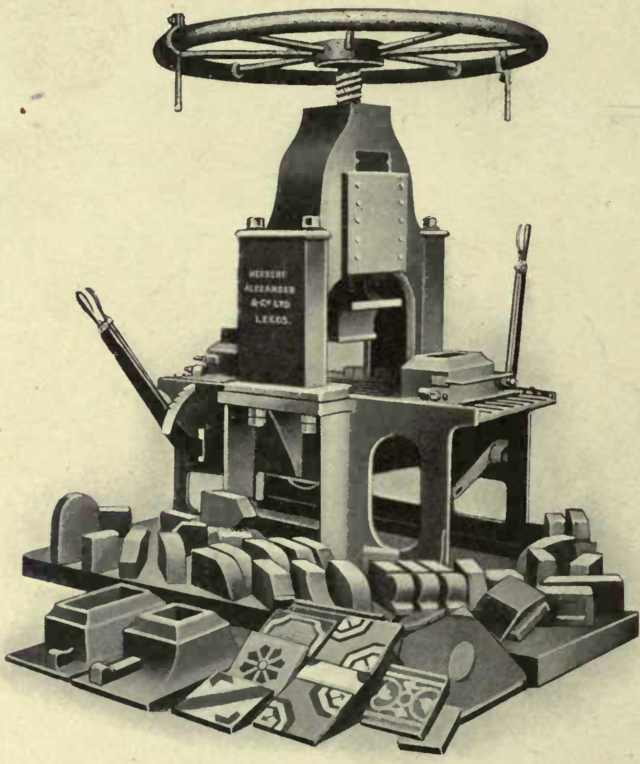


FIG. 45. Fly Press for Ornamental Bricks

It is usually convenient to make the blocks 18½ in. × 9½ in. × 4⅝ in. so that they replace six large or eight small bricks, but slabs up to 24 in. × 12 in. × 4½ in. may be made in existing presses.

The press shown in Fig. 44 has been found to be quite satisfactory for such blocks and for paving slabs up to 20 in. × 10 in. × 3 in. and has an average output of 120 blocks or slabs per hour. It is a rotary table press which exerts a pressure of 250 tons on each block or slab. The makers—Sutcliffe Speakman and Co. Ltd.—are also adapting this press to make hollow blocks up to 18½ in. × 9½ in. × 9 in.

Blocks of an ornamental character may also be made in plaster moulds. The mixture of lime and sand is placed in the mould, tamped tight and then beaten repeatedly with a wooden mallet so as to make it as compact as possible. The blocks are then sent to the hardening chambers, in which they remain all night. Large blocks should be moulded on the cars, collapsible moulds being used, but smaller ones may be lifted on to the cars. "Cupboards" of slabs and bricks are built around the blocks and form shelves on which other blocks can be placed. This method is used with great success by several firms in this country. It is an admirable side line to the manufacture of bricks.

Fancy Moulded Bricks may be made by any of the methods previously described in a hand-driven press (Fig. 45), providing that there is sufficient demand to justify the construction of the necessary moulds.

CHAPTER VII

HARDENING THE BRICKS

THE bricks, as they come from the press, are sufficiently hard to be handled without damage if reasonable care is used, but before they can be used for building purposes they must be thoroughly hardened by converting the compound of lime, silica, and water into an insoluble substance of such a nature that it will bind the grains of aggregate so tightly together that the bricks will resist all the ordinary forces of weather and usage.

It is important not to let the bricks stand about too long before sending them to the hardening chamber. One firm made a serious mistake in this respect and found that their bricks would not harden properly. The reason was quite simple. In order to effect an economy in working, the press, which had a much greater output than the heater, was so worked that sufficient bricks to fill the heater twice over were made at once; and the press was then stopped and the men sent home. Unfortunately, the combined action of the water in the bricks and the carbonic acid in the air convert the lime into chalk, which is not affected by the action of the heater, and in this way the amount of lime available for hardening purposes is reduced in proportion to the time the bricks are exposed before entering the heater.

By rearranging their method of working, and sending the bricks to the heater as soon as they were made, the difficulty of soft bricks was, in the case just cited, entirely overcome.

THE CAUSE OF THE HARDENING. The nature of this binding material or "bond" is by no means definitely known. Formerly, it was considered to be a simple calcium silicate, CaH_2SiO_4 with or without some combined water. Later investigations have shown, however, that its constitution is highly complex.

The water and lime—particularly when the lime is undergoing hydration at a high temperature—appear to attack the grains of aggregate and form a fairly definite compound, the nature of which depends on the composition of the aggregate. In the hardening chamber this action is continued, and at the higher temperature some loss of lime and addition of water occurs, the compound then forming a hard tenacious mass.

The simplest case is that where the aggregate consists exclusively of a pure quartz sand. The surface of the finer grains of this sand is attacked by the lime and water during the preparation of the material, and a compound is formed which is of quite a definite nature, but its binding powers are kept in abeyance by the temperature being too low to admit of its combining with sufficient water to give it cementing properties. Some authorities regard the bond as a soft jelly-like substance formed which has a strong physical resemblance to hot carpenter's glue, and they imagine that during the hardening process this compound becomes heated and then loses some of the water combined with it, thereby shrinking and holding the grains of aggregate in a tenacious grip in a manner precisely comparable to the action of carpenter's glue when two pieces of wood are glued together. Others regard the compound as being greedy for water but unable to combine with sufficient to form a cement, until a higher temperature has been reached (*see* p. 84).

The presence of minute particles of clay in a sand complicates the reaction, and alumina (derived from the clay) is found in the binding material, thus showing that a different compound is produced in the presence of the clay. The compound produced from lime and clay (without any sand) bears a remarkably close resemblance to the essential constituents of Portland cement—one of the strongest bonding materials ever discovered. According to the most recent investigations, the Portland cements are definite but complex compounds of lime, alumina, silica, and water and form a group of closely allied but not identical calcium alumino-silicates. The proportion of alumina in them is quite small—only about 7 per cent.—so that a very small quantity of clay is needed to produce a cement of this character, and the addition of 2 per cent. of clay to a clean sand is ample for the purpose of providing the alumina required. More than 5 per cent. of clay is not satisfactory ; it remains uncombined and weakens the bricks, as it is not in a suitable physical state to make good aggregate.

When working with such small quantities of bond as occur in non-plastic bricks, it is very difficult to isolate the cementing material and to examine it fully. So far as it has been possible to do this, the bond appears to consist of a hydrous calcium alumino-silicate consisting of :

Silica	43.1 per cent.
Alumina . . .	13.1 ,,
Lime	37.2 ,,
Water	6.5 ,,

which corresponds with sufficient closeness to a compound of the formula:

$$6CaO.Al_2O_3.5SiO_2.3H_2O$$

or some multiple of this formula.

The amount of combined water appears to vary greatly. If this composition is correct, and the binding material in lime-sand bricks is as similar to Portland cement as the investigations of the author suggest, the probability is that the production of the lime-sand bond is expressed by some such equation as :

$$15CaO.Al_2O_3.5SiO_2. + 12H_2O = 6CaO.Al_2O_3.5SiO_2.3H_2O + 9Ca(OH)_2$$

This implies that the lime first unites with the aggregate to form an alumino-silicate rich in lime, the compound then reacts with water (or steam) in the hardening chamber in such a manner that some of the lime is replaced by water. The lime set free is then able to combine with more of the material to form a further quantity of bond. This double reaction continues as long as the conditions are favourable or until all the lime is combined in a stable form.

The rate at which the replacement of the lime by water occurs is not constant. The first additions of water are somewhat slow, but the rate increases as the reaction proceeds. If the earlier additions take place too rapidly, the compound breaks up into less complex ones, which are destitute of hardening power. Hence, it is necessary to heat slowly at first. The rate of hardening is also affected by the size of the particles—the larger they are the more difficult it is to hydrate them. A definite degree of fineness of the bond particles is, therefore, an essential condition of hydration and of hardening.

If the particles of binding material are some distance apart the rate of hardening will be reduced, and the combination with water will occur more slowly. For this reason, mixtures which are rich in Portland cement cannot be satisfactorily hardened by steam, whilst those containing a smaller proportion of cement harden quite satisfactorily and rapidly. This fact also explains why lime-aggregate bricks may be hardened with steam whereas rich concrete cannot be treated so satisfactorily, but must be allowed to harden slowly at a low temperature.

The experimental work of F. F. Wright, at the Carnegie Institute, led him to conclude that the binding material in lime-sand bricks is a hydrous lime silicate somewhat akin to the zeolites. These substances are somewhat similar to Portland cement, but are less complex in structure. If F. F. Wright had worked on a large scale and with better facilities he would probably have realized that his experiments afford a much stronger confirmation of the composition suggested by the author of the present volume than they do of the existence of a zeolite as the latter, as far as is known, do not possess cementitious properties.

The general accuracy of the author's conclusion may easily be proved by a synthetic experiment in which the purest quartz grains obtainable are mixed with pure lime and china-clay so as to produce a mixture correspondingly as closely as possible to the formula previously mentioned or to a good quality of Portland cement. If the materials are ground to a fine flour and then hardened by steam under pressure the product will be found to bear the closest possible resemblance in every way to Portland cement which has been moistened with water and then allowed to become hard. Such an experiment is clearly worth far more than any number of theoretical speculations based on a very slight experimental basis.

Where the sand and lime are both free from alumina—a very rare occurrence—the lime and silica appear to be able to combine to form a complex molecule possessing cementing properties, but the bricks made by the author from specially selected quartz and lime of unusual purity were less strong than those made from the same materials to which 2 per cent. of china clay had been added in order to supply the requisite alumina. As 0.7 per cent. of alumina is all that is required for the 6.5 per cent. of lime usually employed, and so small a proportion of alumina is easily overlooked, it appears reasonable to suppose that its importance has not previously been realized, though several makers of lime-sand bricks have noted the improvements effected by the addition of a little clay to the raw material used.

When the aggregate consists of a complex material such as clinker or slag it will usually be found that it contains a considerable proportion of pozzolanic material, *i.e.* of substances which combine with lime and water to form calcium alumino-silicates closely allied to the Portland cements. Hence, in bricks made of such materials the complex silicate is probably formed during the mixing of the materials, and during the hardening its partial hydration and "setting" are effected in the same manner as in Portland cements and in lime-sand bricks.

In short, whatever may be the nature of the aggregate used, good bricks made from it will consist of grains of various sizes bound together by a matrix of hydrous calcium alumino-silicates possessing properties very similar to those of Portland cement, and superior to bricks made with commercial Portland cement in proportion to the difficulty experienced in mixing the latter uniformly with the aggregate.

METHODS OF HARDENING. As explained above, the hardening of non-plastic bricks consists essentially in adding a definite proportion of combined water to the compound which forms the binding material so as to form an equally definite hydro-alumino-silicate. This combination can only occur under suitable conditions of temperature and humidity.

If the temperature is sufficiently high but no steam is present, too much water would be removed from the bond; if steam or water was used at too low a temperature the rate of hardening would be so slow as to be unprofitable even if the hardening was completed to a sufficient extent to produce useful bricks.

With *lime-sand bricks* the ideal conditions for hardening appear to be a temperature of 300° F. or 150° C. with steam at a sufficiently high pressure to provide the requisite humidity. These conditions may be obtained by placing the bricks in a strong steel chamber * or autoclave and heating it with live steam at a pressure of 120 lb. per square inch., and maintaining this pressure in the chamber for eight to ten hours. A longer heating at 392° F. or 200° C. produces stronger bricks by utilizing a larger proportion of the bond present, but this greater pressure is quite unnecessary for all ordinary purposes, and the pressure of 120 lb. per square inch inside the chamber is generally adopted and has proved quite satisfactory. Where a shorter period of heating is essential a pressure of 200 lb. per square inch for five hours may be used.

* The autoclave should be well covered with a non-conducting material, such as asbestos, so as to retain the heat; otherwise the amount of steam used will be very excessive.

With bricks made of *granulated slag*, two distinct methods of hardening may be employed:

(*a*) *Air hardening*, in which the bricks are sheltered for two or three days and are then stacked in the open air for three months or more. This method of hardening is possible because pozzolanic materials, such as wet granulated slag, possess hydraulic powers when mixed with lime; that is to say, they form a compound analogous to Portland cement without requiring to be heated, but the rate at which this substance combines with water and hardens is much slower at the ordinary atmospheric temperature than when artificial heat is used. Apart from the rate at which the hardening occurs there is no important difference, the composition of the cementing material being almost the same in each case.

(*b*) *Steam hardening*, which is effected by steam in autoclaves, when the reactions occur as previously described. With bricks made of granulated slag a low pressure of steam may be used, providing its action is continued for twenty-four to forty-eight hours, according to the nature of the slag. If high-pressure steam at 120 lb. per square inch is employed only eight hours are needed for the hardening process.

Bricks made of *dry ground slag* may be hardened in one of three ways:

(*a*) *Air hardening*, as described above, but seldom satisfactory for this kind of brick.

(*b*) *Steam hardening*, as described on p. 86, and usually the safest and best method.

(*c*) *Carbonic acid hardening*, which, as utilized by F. Dressler, consists in exposing the bricks to the action of waste gases from gas-engines under a pressure of 15 lb. per square inch. These waste gases are rich in steam and carbonic acid, so that two entirely different kinds of hardening occur:

(i) The combination of the free lime and the carbonic acid to form a complex basic carbonate similar to that produced when building mortar hardens in air.

(ii) The formation of a hydro-alumino-silicate similar to that produced when the bricks are hardened by steam.

Dressler's method of hardening is chiefly used where the supply of water is very limited or where gas is more readily obtainable than steam. Whilst the bricks are apparently of equal quality to those hardened by high-pressure steam, the latter process is generally found to be the more satisfactory where both are equally available.

Clinker bricks may be hardened:

(*a*) By pressure steam, in the same manner as lime-sand bricks.

(*b*) By low pressure steam, as described on p. 88.

(*c*) By air hardeneing as described above.

An interesting confirmation of the theory of hardening suggested in the foregoing pages is shown in the two following analyses of bricks in which *A* is brick made of destructor clinker and 8½ per cent. of quicklime; *B* is a concrete made by adding one part of Portland cement to five parts of the same destructor clinker :

	A	*B*
Lime	17.0 per cent.	16.8 per cent.
Silica	32.5 ,,	32.2 ,,
Alumina	14.8 ,,	14.1 ,,
Ferric Oxide	18.2 ,,	16.8 ,,
Magnesia and Alkalies . . .	5.5 ,,	5.8 ,,
Water in combination . . .	12.0 ,,	14.3 ,,
	100.0 ,,	100.0 ,,

A comparison of the figures for the two kinds of bricks will show that they are identical though the bricks were made by two entirely different methods.

Hardening Chambers. The hardening of the bricks by steam is most satisfactorily effected in a hardening chamber or *autoclave,* a works with a very large output requiring several of these chambers. They are usually cylindrical in pattern and somewhat resemble an ordinary steam boiler. One or both ends is provided with a door which can be fastened in an air-tight manner by means of screws, of which about forty are usually required. The diameter and length of the chambers vary according to the output required, it being usually best to maintain an average diameter of 6 ft. and to make the length correspond to the number of bricks to be hardened each day. It is seldom desirable to have a cylinder with a length more than five times the diameter.

It is important to point out that the best size of hardening chamber is one 6 ft. in diameter. Many makers of plants specify chambers 6 ft. 6 in. in diameter. The cost of making a 6 ft. 6 in. chamber is less than that of a 6 ft. chamber to contain the same number of bricks owing to the latter having to be longer. But a 6 ft. 6 in. chamber is really too large for the man stacking the bricks, and also demands a big waggon load of bricks, so that in the end it is more costly and less satisfactory than a chamber 6 ft. in diameter.

Although the usual and most convenient size of hardening chamber is 6 ft. to 7 ft. diameter, much smaller ones may be more satisfactory under certain conditions. Thus, in tropical countries—where the difficulty of transport is great—or in localities where the first cost must be reduced even at the risk of a slightly less economy in daily working, it is better to use a chamber only 3 ft. in diameter and to have the steam at a pressure of 200 lb. per square inch for about half the time ordinarily required by steam at 120 lb. per square inch. To secure the necessary economy with these smaller chambers, they must be operated day and night continuously and must be arranged so that when the contents of one chamber are finished the surplus steam can be discharged into another chamber which has just been filled.

The general construction of the hardening chamber should be such that it will pass the inspection of a good boiler insurance company, and as explosions may occur it is wise to have it properly insured. It is essential that the chambers should be well built of stout plates or the risk of explosion may be serious and the life of the chamber will be short. Two other features which also require attention are the amount of steam needed, and the method of fastening the doors when the chamber is full of bricks. The former depends chiefly on the design and construction of the cylinder, it must be made to hold the largest possible number of bricks, so that there is no lost space to be occupied solely by steam. The probable efficiency of a hardening chamber can be most readily ascertained by noting how many bricks can be placed in it, and by ascertaining what advantage, if any, would be gained by making it a few inches larger or smaller. To a large extent this is a matter which must be left to an expert to decide.

It is important that the doors should be made specially strong to stand the steam-pressure. They should have no spring when under full pressure of steam; there is then no difficulty in making steam-tight joints, using only an 18 in. spanner, whereas a door which is not rigid under pressure will spring off the joints and cause leakage.

Various methods of fastening the doors of the chamber have been devised, but the most generally satisfactory consists of hinged bolts fitting into slots on the door, and clamping it on the flanged end of the chamber. This arrangement is shown in Fig. 46, the door being raised on a single bar by means of a hand-driven gear, or being lifted out of the way by means of an ordinary block and tackle. Various arrangements for fastening the doors in a more rapid manner than by the use of some forty screw-bolts have been devised, but though the author is practically acquainted with most, if not all of them, he has yet to find a method which is more rapid and, at the same time, as durable and satisfactory as the one recommended.

Ordinary live steam is generally employed, but several investigations into the use of slightly super-heated steam have shown that better results may be obtained by its means. The danger of overdrying the bricks is insignificant if the superheating is not excessive, and the avoidance of waste by condensation is more than sufficient to compensate for the cost of supplying additional heat to the steam.

When ordinary live steam is used it should be maintained in the hardening chamber at a pressure of at least nine atmospheres (120 lb. per square inch). The length of time the bricks remain under this pressure depends largely on the size of the sand grains, and on the extent to which the lime has been pasted over them. Hence, it must be determined by actual trial. Some bricks are made of such excellent material that an exposure of eight to ten hours at a pressure of 120 lb. per square inch is sufficient, but others need a much higher pressure and a longer exposure. It may, however, be taken for granted that bricks which require a longer treatment than ten hours can usually be improved by a better method of treating the material previous to its being made into bricks.

All hardening chambers should be fitted with a safety-valve to blow off at a pressure of 125 lb. per square inch.

Where *low*-pressure steam is employed, tunnels made of bricks are quite satisfactory. No iron casing is needed, and brick tunnels are cheaper to instal than high-pressure chambers, but they occupy much more ground and the quality of the

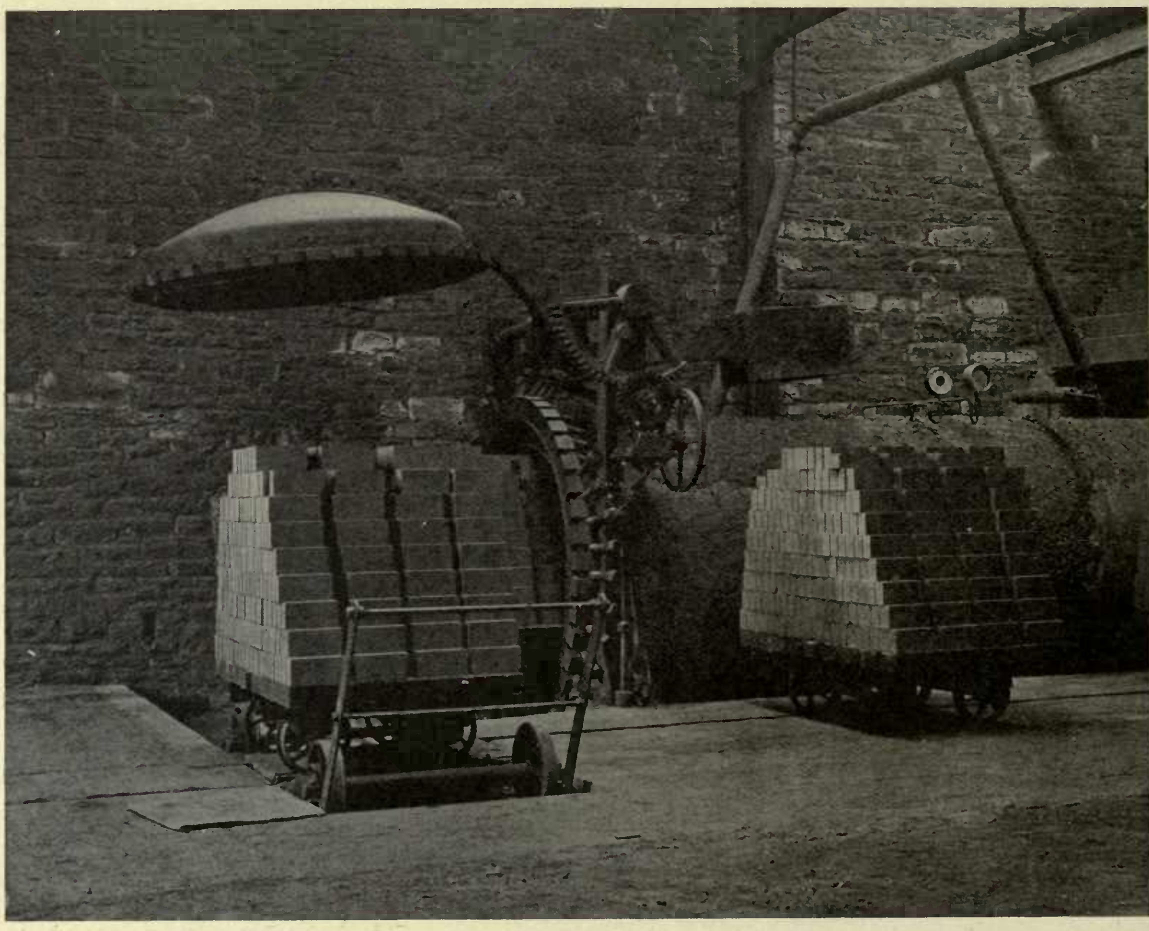


Fig. 46. Bricks entering Hardening Chamber
Courtesy of Sutcliffe, Speakman & Co. Ltd.

bricks is seldom quite so high as when steam under a greater pressure is used (*see* Figs. 20 and 22).

Boilers. For the production of steam it is essential to have a boiler of suitable pattern and capacity. Water-tube boilers are not satisfactory, as they do not possess sufficient reserve. The best boiler for the purpose is a 30 ft. "Lancashire" or "Yorkshire" boiler working at 130 to 150 lb. per square inch pressure. It may advantageously be fitted with a mechanical stoker, and a feed-regulator for keeping the water-level constant.*

* The "Thermofeed" device is excellent for this purpose.

The water should, preferably, be softened before it enters the boiler; this saves endless trouble later and is cheaper than the addition of anti-scale preparations to the contents of the boiler.

Cars. The bricks in the hardening chamber are placed on low flat cars on which they can be stacked close together. Each car is arranged to hold 600 to 900 bricks, but in some cases smaller cars are desirable.

Fig. 47 shows a series of cars each 5 ft. 4 in. wide and 3 ft. 3 in. long and holding 650 bricks. These cars are excellent for clinker bricks and for medium outputs, but they are less than those ordinarily employed for lime-sand bricks. Some firms prefer them, however, as they may be moved about more readily than the larger cars. The same illustration and Fig. 48 show how the bricks are placed on the cars.

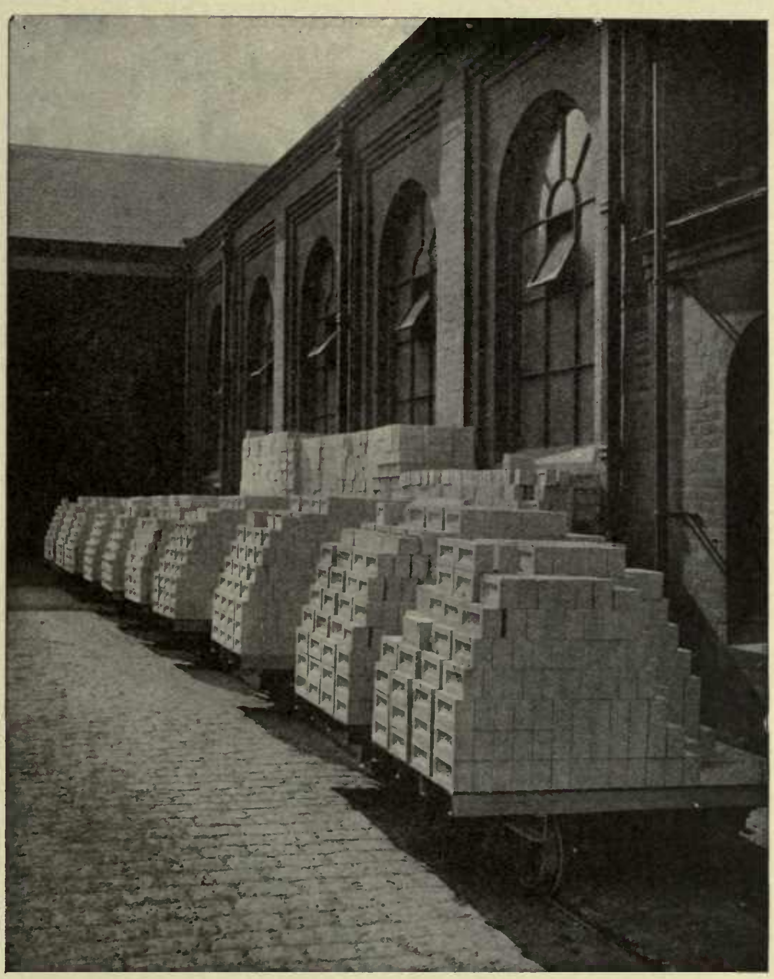


FIG. 47. Cars loaded with Bricks
Courtesy of Sutcliffe, Speakman & Co. Ltd.

The diameter of the hardening chamber will largely determine the maximum width of the cars, but it is a mistake to make them too long. The earlier cars used for lime-sand bricks were so large and cumbersome that half a dozen men were needed to move them. Modern cars are much smaller, and are fitted with roller bearings so that with a full load of 900 bricks they can be readily moved by a single man.

When *low-pressure* steam or *air-hardening* is used, the bricks should not be set so closely together as when hardened by high-pressure steam. Moreover, the time they require to be kept in the hardening tunnels would make the use of cars excessively costly. In such circumstances it is better to stack the bricks on steel pallets or wood-and-steel pallets each holding about fifteen bricks. Twelve of these pallets are supported on a transfer car immediately in front of the press upon suitable stands which permit of the pallet when loaded being raised by a special lifting waggon (Fig. 48). This waggon being pushed beneath the pallet, a hand-wheel actuating a screw and system of levers is then turned, lifting the pallet clean off the stands. The waggon with its loaded pallet is now wheeled into the hardening chamber, the hand-wheel again being turned, this time lowering the pallet and its load on to the supporting side walls of the tunnel, when the waggon is removed. After the steaming has been effected, the same procedure for removing the pallets from the chambers is adopted.

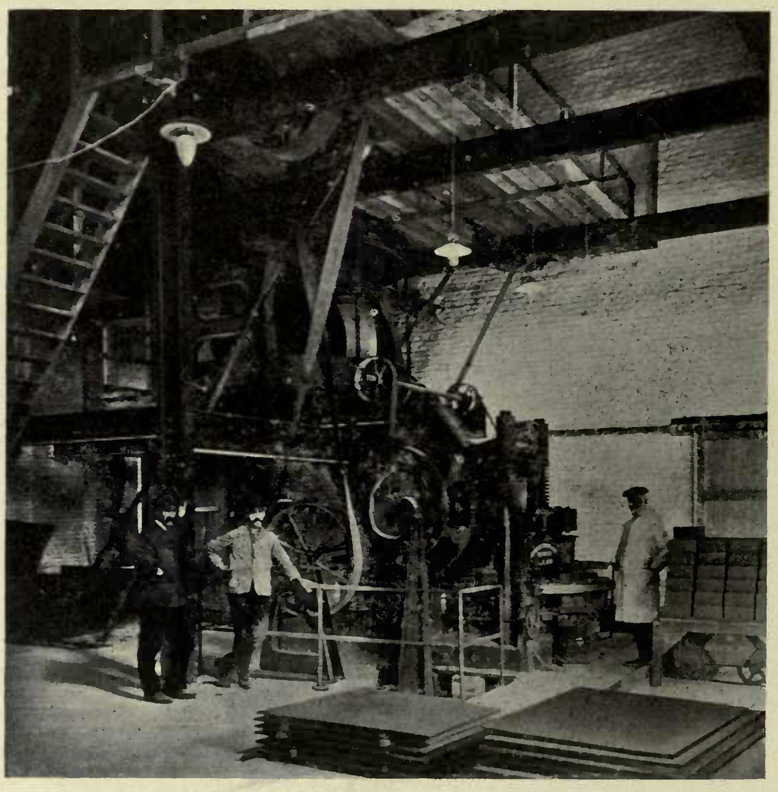


FIG. 48. Press with Pallets and Special lifting Waggon
Courtesy of Sutcliffe, Speakman & Co. Ltd.

This waggon may also be used for handling the bricks for air-hardening, particularly where it is found advisable to permit the bricks to receive their initial hardening before setting in the usual close piles for maturing. In some works, bricks to be air-hardened are taken on cars directly from the press to a shed where they stay for a couple of days and are then stacked in the open air.

In *low-pressure hardening* (Figs. 20 and 22) the bricks from the press are placed directly on to a car, and when this is full it is taken along the rails to the hardening chamber. Each chamber holds several cars, and when it has been filled, the end of the chamber is lowered into position and fastened tightly to prevent leakage.

The steam is then turned on slowly so as to heat the bricks and chamber without causing any needless condensation on the former. The amount of steam entering the chamber is then increased gradually, until, finally, the full pressure of 120 lb. or 200 lb. per square inch is reached and is maintained for eight to ten hours or four or five hours according to the steam pressure.

As soon as the heating period is over, the steam supply is cut off, the pressure is released by opening the valve provided for the purpose, and the contents of the chamber are allowed to cool. The chamber is then opened, the cars are withdrawn, and the bricks may either be loaded on to carts waiting to take them away, or preferably they may be stacked in the yard until sold. The longer they are kept before use the stronger will they become, but if properly made they are quite fit for use directly they come from the hardening chamber.

Carbonic hardening is effected in brick-lined tunnels (Fig. 20), the procedure being similar to that in autoclaves, except that waste gases from gas-engines are substituted for the steam ; a period of about ten hours is required.

OVERSIGHT. The men who know and who are demanding high-class goods realize that there is more in the way bricks are produced than was at first supposed.

Experience has shown that it is economical and good practice to keep all machinery in first-class condition for the work required of it. It should not be neglected, but the repairs should be made promptly and the liners of the press watched, for, otherwise, the presses will not give good service.

SORTING. The bricks should always be sorted carefully if there is a notable variation in their appearance—due to accidental carelessness or to defects in manufacture. If the works are properly managed, however, this sorting should be unnecessary.

PACKING. Bricks made of sand, slag, or clinker should be *packed* into carts and not thrown into them or their edges will be damaged and their appearance spoiled. This must not be understood to mean that these bricks are any less strong than those made of clay ; it is merely a suggestion as to one means of avoiding the production of damaged bricks.

CHAPTER VIII

CONCRETE BRICKS AND BLOCKS

THE manufacture of bricks and blocks in which the binding material is formed by the addition of lime, requires an extensive plant which may cost £4000 to £5000. Hence, where only a small outlay for plant is available, Portland cement * may be substituted for lime, and a different product, but one which in many cases satisfactorily meets the requirements of users, obtained.

Bricks and blocks made from sand, slag, clinker, or other non-plastic material as aggregate and Portland cement as binding agent are known as *concrete bricks and blocks*, † as they are made in a similar manner to concrete, some modifications being necessary for small blocks and bricks.

The *aggregate* must be reduced to particles of suitable sizes and must be properly graded (p. 8). If rock-clinker or dry slag is used, the lumps must be crushed between rollers (Fig. 8) or in a jaw-crusher before any grading is attempted.

The sizes of the particles depends on the size of the blocks or bricks to be made. For bricks, all must pass through a $\frac{1}{4}$ in. mesh, and to obtain good results in concrete blocks, the gravel and crushed stone should not run larger than from half to three-quarters of an inch. The proportions of the various sizes should be as nearly accurate as can be obtained by careful grading as described on p. 8. It is not wise to use a powdered aggregate for blocks larger than bricks, as a better product is made by the use of a coarser material, such as gravel, along with the powder. Even with bricks, a little fine gravel is often an advantage along with the sand. Where thin blocks or slabs are to be made no very coarse particles of aggregate should be allowed.

It is very essential that the aggregate used for the manufacture of bricks should be sharp, not soft, and not very fine. This is necessary, because the mixture used for bricks is a very poor one, 1 to 7 or 1 to 8, and in some cases even 1 to 9.

As a matter of fact whenever sand is used for concrete it should always be sharp, but especially so in all cases where poor mixtures are used, whereas in rich mixtures like 1 to 3, the great amount of cement used may make up for the softness of the sand.

* It is important to note that Portland cement should be used and not any of the others such as Roman cement, etc. For notes on Portland cement, *see* the footnote on p. 101.

† In America they are known as *cement bricks*, but this term is misleading, as the proportion of cement should not exceed 30 per cent. of the whole material.

Sand for concrete bricks and blocks should be reasonably coarse and sharp ; it should be free from all loam or as nearly so as possible.

The ideal sand is one which passes a sieve of $\frac{1}{4}$ in. mesh and is retained on a sieve of $\frac{1}{64}$ in. mesh, and in which all the intermediate sizes of grain are contained. For some products, however, as for instance roofing tiles, nothing larger than $\frac{1}{8}$ in. should be used.

Care should be taken in the selection of these materials. If necessary, to obtain good results, the materials should be washed.

The proportion of *Portland cement* required depends upon the aggregate. If this consists of sand or crushed rock, about one measure of cement to each six to eight measures of aggregate will be needed. Mixtures richer in cement are seldom necessary and are often less satisfactory. When the blocks are required to be specially resistant to water, a mixture of one part of Portland cement to three parts of sand may be used, but it is much better to employ this mixture for facing, rather than for the whole of the block. In no case should blocks be finished with pure cement, as this causes shrinkage, cracks, and a phenomenon known as "alligatoring" (see *Defects*, p. 123).

One measure of cement to seven measures of clinker will often be sufficient, but much depends on the method of mixing as well as on the nature of the aggregate. Thus, when a hand-mixed material is used, the bricks or blocks may be made of one part of cement, two of sand and three of aggregate between $\frac{1}{2}$ in. and $\frac{3}{4}$ in. diameter. Such blocks may be faced with a mixture of one part of cement and two of sand.

Particularly good results may be obtained by first grinding the cement with twice its measure of sand, so that the mixture passes completely through a sieve with eighty to ninety holes per linear inch. Blocks may be made of the following :

Cement-sand mixture . .	3 parts
Sand	4 ,,
Aggregate	5 ,,

These blocks may be faced with cement-sand mixture, which gives a beautiful waterproof surface. If blocks made of this material are hardened by steam in an autoclave (p. 86) they will have a crushing strength nearly double that of similar blocks made of one part of cement to three of sand hardened in air for a year in the usual manner.

Slags vary greatly in the amount of cement needed, as some of them possess cementitious properties themselves ; and only need to be ground and mixed with water to make them ready for use.

In mixing the materials for brick making great care should be taken that sufficient water is added. It is desirable to use as much as possible, but not so much as to cause the bricks to " buckle " when leaving the machine. It is impossible to give definite figures with regard to the amount of water to be used, for the quantity necessary will vary from time to time. By working carefully the men are sure to find out very quickly whether the mixture is too soft, though this is less serious than making it too dry.

One of the first considerations should be the storage of the cement. The size of the bin or warehouse will depend, of course, upon the output, but in no case should it have a capacity of less than 300 barrels. The floor should be raised off the ground, and should be a double floor with an air space between (Fig. 7). The ceiling should also be double ; the windows should have extra doors so they can be closed and the room kept dark. The cement should never be piled against the wall. This will prevent waste in cement and complaints against the cement manufacturer as to the grade of his cement. The men should never unload a car of cement in the rain, except under cover. The sand and gravel sheds should be large enough for a week to ten days' run, and if possible should hold larger quantities for use in the winter months. To be able to manufacture concrete blocks and to sell them at a profit, the plant must be properly arranged and the equipment as nearly perfect as possible.

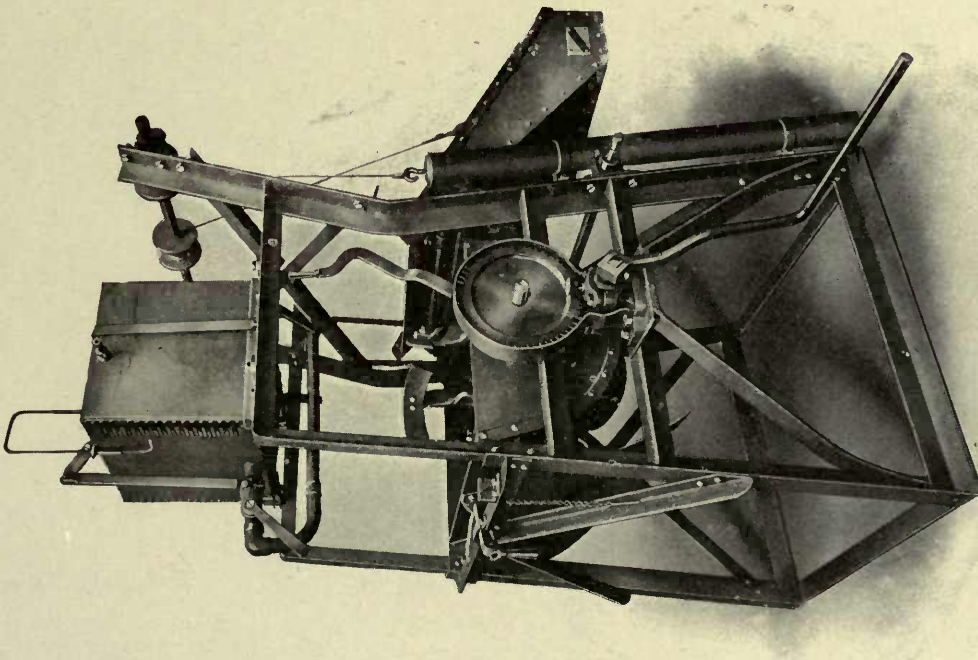
Where specially *waterproof* blocks or bricks are required as much trass or finely ground brick-dust may be added as is equal to the cement used. This added material combines with the lime set free when the cement hardens and renders the material impervious. Blocks made of such a mixture are specially suitable for use in coastal work as they do not corrode in sea water.*

The *mixture* used for making cement blocks and bricks is made by placing the necessary quantities of aggregate and cement in a mixing machine and working the latter until a uniform material is obtained. The necessary quantity of water is then added and the mixing is continued until a homogeneous paste is produced. This is better than adding the water at first and produces stronger articles. The second mixing must not be unduly prolonged or the cement will begin to set and will be spoiled. It is scarcely possible to mix the materials effectively with spades on a board, and attempts to do this was one of the causes of failure in the early days of concrete bricks. With perfectly conscientious men spade mixing is satisfactory, but it is seldom that such men will remain as reliable as at first.

If the output is small, a hand-driven mixer such as that shown in Figs. 49 and 50 may be used, but for larger quantities a power-driven mixer (Fig. 26) is preferable. The size of the mixer will be determined exclusively by the number of moulds in use, as the mixture cannot be stored, but must be used immediately. It is, therefore, necessary to produce only just as much paste as the moulds or presses can use, for if it stands for more than an hour before use, the setting qualities will be damaged and the bricks or blocks will be weak.

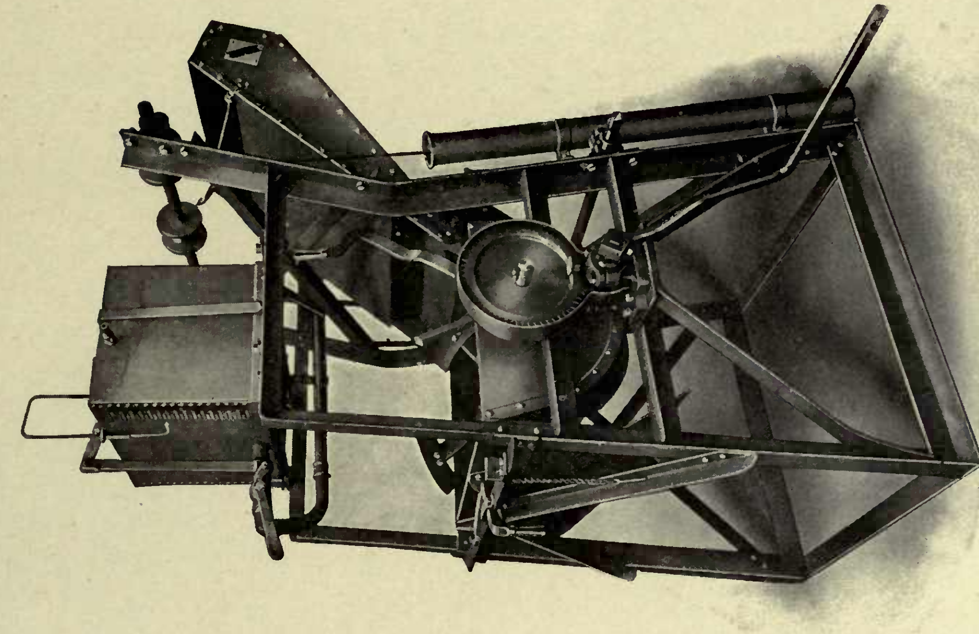
For the press shown in Fig. 56 the power mixer recommended by the (U.K.) Winget Co. Ltd. as the most suitable is the "Express" mixer shown in Fig 51. This consists of a stationary pan 6 ft. 6 in. in diameter, and 1 ft. 9 in. deep,

* The advantages of the use of trass or brick-dust are clearly and fully explained in "A Manual for Masons," by J. A. van der Kloes and A. B. Searle (J. & A. Churchill, London).



The (U.K.) Winget Concrete Machine Co. Ltd.

FIG. 49. Hand Mixer



The (U.K.) Winget Concrete Machine Co. Ltd.

FIG. 50. Hand Mixer

in which a series of ploughs and rakes revolve and mix the contents of the pan.

For a power-driven press making a larger quantity of bricks or blocks, it is often advisable to have a mixer of the type shown in Fig. 26, and 6 ft. diameter.

The *shaping* of the bricks or blocks may be effected by hand in moulds, or in presses. The former are best where a few blocks of a special shape are needed, but for a large output some form of press is necessary.

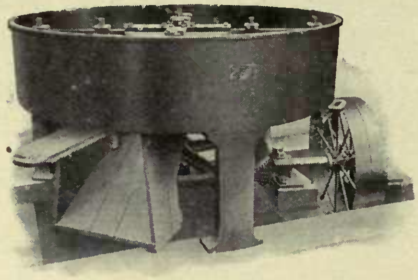


Fig. 51. Express Mixer
Courtesy of (U.K.) Winget Co. Ltd.

The *moulds* are rectangular frames of iron or mild steel. They are filled with the pasty mixture and the surface is then gently tapped with a special mallet termed a tamping iron, so as to fill the mould completely. As soon as this occurs and a film of water has risen to the surface of the concrete, the tamping is stopped and the man moves to the next mould. After a suitable time, when the cement has set sufficiently, the sides of the mould are loosened and the block or brick is removed and stored in a shed until hard enough for use, from one to three months storage being usually necessary.

A useful mould for bricks and small blocks, sold by R. Baumgarten of Lewisham, is shown in Figs. 52 to 54, which are self-explanatory.

Fig. 52. Mould ready for use

The *presses* used for making concrete blocks and bricks are of numerous patterns. Some (chiefly used for bricks and small blocks) are worked by hand, but the more powerful ones (used for large blocks) are mechanically driven. Very great care should be taken in selecting a press, as several on the market—especially those offered by small firms—are far from satisfactory, and as a general rule power-driven presses are unsuitable for concrete work, as they require too dry a mixture and make too porous a product.

Power Tampers. Brick- and block-making machines in which the concrete is tamped by power-driven rams need less workmen, and these can be quite unskilled. These power tamping machines are only useful where the demand is very large; otherwise the cost of the machinery is so great that the interest and depreciation charges become a serious item, and hand-tamping is cheaper.

Hand-worked presses are of three main types:

(*a*) Those in which the bricks or blocks are made on a wooden pallet on which they are dried. These wooden pallets soon twist in use, and the bricks made on them are liable to twist and crack. Such machines are, therefore, unsatisfactory.

(*b*) Those in which the moulds are inverted directly on to the drying floor or on to iron pallets. These are satisfactory for blocks of medium size, but for bricks they are too slow to be profitable.

(*c*) Lever-machines in which several bricks or blocks are made at once each in a separate mould-box and delivered on to an iron pallet. For bricks, machines making six pieces at a time are convenient and satisfactory and do not tire the workmen. An excellent machine of this type is the "Lausitz" machine sold by R. H. Baumgarten of Lewisham and shown in Fig. 55. In this machine each brick is made on a separate iron pallet and remains thereon for two days, after which the

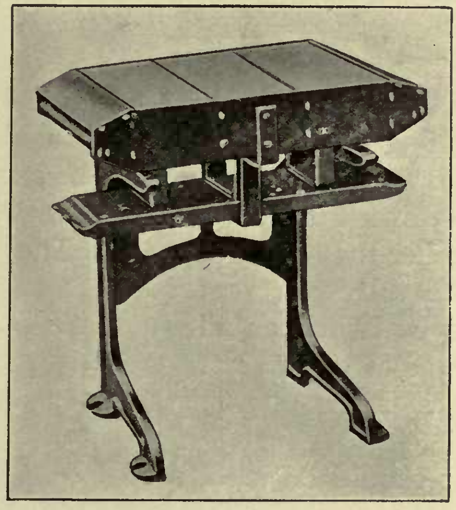


FIG. 53. Mould filled and tamped

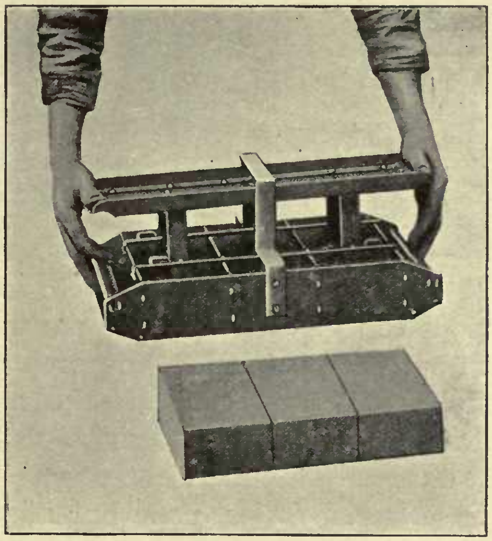


FIG. 54. Mould inverted, loosened and empty

bricks can be stacked on each other and the pallets used for fresh bricks. Two men can prepare the mixture and make 3000 bricks per day with one of these machines.

Among the best of the hand-lever presses is the machine shown in Fig. 56, which consists of a mould-box with hinged sides and ends carried on the frame hung in trunnions, as shown, with core blocks set inside. When the lever at the right-hand side of the illustration is pulled down, the bottom of the mould-box (which is formed with a loose pallet inserted for each block) is lifted up, and at the same time the sides of the box fall outward, leaving the finished block on the pallet ready to be carried off. When it is required to use the machine in the face down position, the frame carrying the mould-box is swung over in the trunnions into a horizontal position with the same lever on releasing the stop controlled by the small horizontal lever at the right-hand side of the machine. The cores are carried on a fixed bed plate under the pallet forming the bottom of the mould box.

The movements necessary to make a block are the fewest and simplest possible, so that the maximum output is secured with a minimum cost for labour. If the instructions given with the machine are followed, two men can make about 400 or 800 slabs per day.

A typical power-driven press for concrete blocks and bricks is shown in Fig. 44. This is specially suitable for blocks of a size to take the place of six large or eight small bricks, viz. $18\frac{1}{2}$ in. in length, $9\frac{1}{2}$ in. in width, and $4\frac{3}{8}$ in. in thickness, and the press is capable of making up to 1200 such blocks in a day of ten hours. It may be used to produce blocks with a face resembling dressed stone as shown in Fig. 43. When clinker or slag is used as the chief aggregate, the blocks may be faced with a sand-cement concrete as described on p. 80. The usual proportions vary from one and a half to three parts of aggregate to one part of cement. When ordinary sand is used it should be graded from $\frac{1}{8}$ in. down to No. 50 mesh, with no material smaller than No. 100 mesh. The proportions can be as low as one part of cement to three parts of sand, but in white facing, the proportions must be richer, as all available white aggregates are either all one size, as in the case of white sand, or contain too much fine material, as is the case in most crushed white marble.

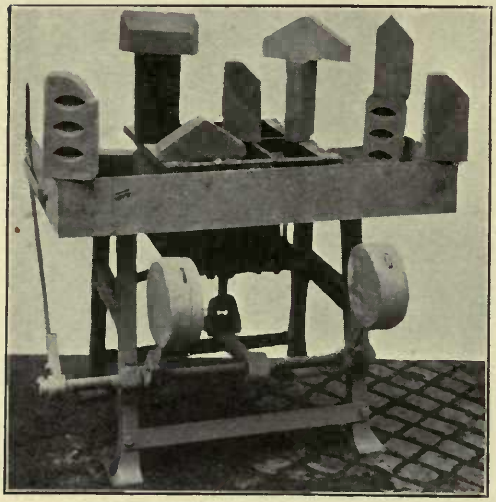


FIG. 55. Lausitz Brick Press

In *coloured facing*, none but mineral colours should be used. With proper materials and care it is possible to use as high as 40 per cent. colouring in the proportions of one part cement, half part colour, and one part aggregate. Dark, deep shades cannot be obtained except with a large percentage of colouring.

A recent innovation is that of the *granite facing*. This is becoming very popular, and is being used in large cities for public buildings, for which the ordinary block would not be considered under any circumstances. The best proportions found for granite facing are one part of cement to two and a half parts of granite. The granite should pass a $1\frac{1}{8}$ in. screen and be graded to about $\frac{1}{32}$ in.

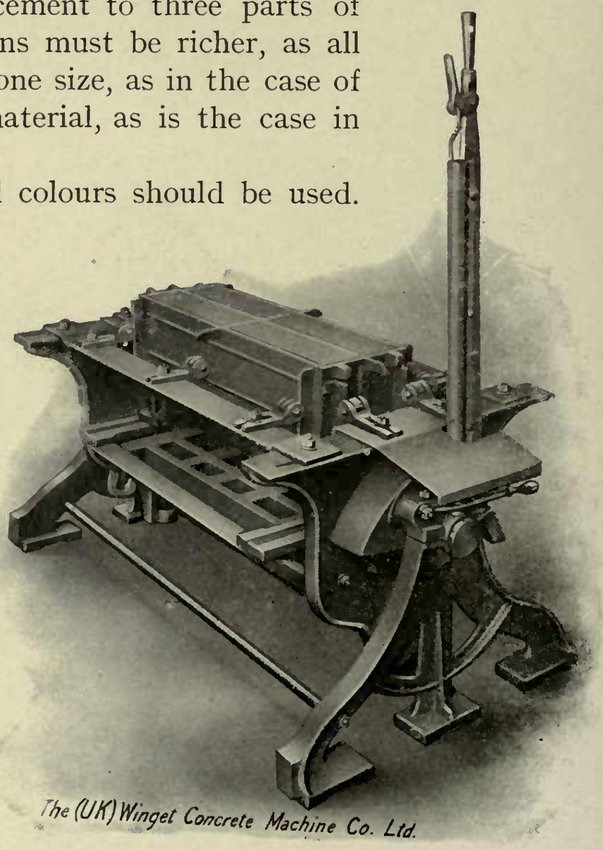


FIG. 56. Winget Brick Press

In addition to bricks and blocks it is equally possible to make roofing tiles, floor-tiles, hollow partition slabs, and even agricultural drain-pipes in the same manner. The operations for making roofing tiles in a "Wilhelma" machine * are shown in Figs. 57 to 60, and are as follows :

After the pallet has been placed in the machine the workman puts on it just

FIG. 57. Filling the Mould

FIG. 58. Tamping the Tile

FIG. 59. Applying Colour

FIG. 60. Releasing the finished Tile

FIGS. 57–60. Making Concrete Roofing Tiles

Courtesy of R. H. Baumgarten

one shovelful of mixed material (Fig. 57). He then tamps down and shapes the surface of the tile by means of a shaped bar (Fig. 61). This action is illustrated by Fig. 58. After the tile has been given the correct shape and a smooth surface, the colour sprayer is moved over the surface of the tile, and by one quick movement an even layer of colour mixture (consisting of ten parts, by weight, of cement and one part of cement colour) is spread over the surface (Fig. 59), and is rubbed into it

* Sold by R. H. Baumgarten; Lewisham.

by means of the shaped bar, which at the same time forms a kind of glaze on the tile. The man then releases the tile by pressing on the foot lever (Fig. 60), lifts the tile and pallet, and then places them on a rack to harden.

Two days after the tiles have been made they can be taken off the pallets and stacked. They should not be sent out or placed on the roof before they are six weeks old.

In making moulded blocks of non-plastic materials it is essential to limit the number of patterns and sizes offered for sale as otherwise their production will be unprofitable, the tendency of builders and architects being to make the manufacturer carry stock of each pattern they may chance to require, and to ask for fresh patterns every few months. A calculation should be made showing the cost of each fresh mould for different numbers of blocks made from it, and the prices of these blocks should be charged accordingly. Unless this is done scrupulously the manufacturer will find that it would have been better if he had never made fancy blocks at all.

FIG. 61. Tamper for Tiles

The paste is fed into the moulds of the press by hand by means of a scoop which holds rather more than a mould. Whilst one mould is being filled the material in another is being pressed and the brick is being removed from a third, so that the machine operates in a perfectly simple manner, exerting a pressure of 250 tons on each block.

The *hardening* or *curing* of concrete blocks requires a month or more, but as they are simply stacked under cover the only cost is the interest on the capital tied up.

If the blocks have a tendency to dry unduly during the first month they will be improved if watered, with an ordinary watering-can, on the exposed sides. Should the aggregate be very dense, the concrete may not contain sufficient water to harden properly. In this case the blocks should be made thoroughly wet as soon as they can be after they are moulded, and the water should be made to permeate every part of the block. Just to sprinkle the surface or top will not do at all, for it is possible in this way to produce a good hard crust about one-half inch thick, where the moisture gets to the block, while the protected surfaces where the water never reaches remain almost as inert as were the materials before it was put into the moulding machine. Such curing merely makes a hard crust for an inside quantity of sand. This crust soon becomes practically impenetrable, so that the finished block really has no quality except as expressed by this outer shell or crust.

In hot weather the blocks or bricks should invariably be placed under a shed where they are protected from the direct rays of the sun, and repeatedly drenched with water for at least seven to ten days before they are allowed to dry out. It is quite as important to season the back of the block as the face, and the core holes should also be drenched with water for the same reason, especially the tongues, which extend from the outer to the inner plate of the blocks. Without a complete and intelligent seasoning of all the blocks manufactured, it is preposterous to look for success in the manufacture of dry mixed building materials. Water, and plenty of it, is the indispensable factor, not only in the mixing, but after the goods have been made they should be kept wet for a month or more.

No heating or other treatment is necessary, though the blocks should not be exposed to frost within three months of their being made.

The various changes which occur when cement sets and a concrete hardens are highly complex. Without describing them fully, it may be stated that part of the lime in the cement compound is set free and is replaced by an equivalent of water, with the formation of a fresh crystalline compound. The replacement must take place slowly at first or no true hardening will occur.*

In many respects the hardening of concrete resembles that of lime-sand bricks, but the latter is effected more conveniently in a steam-heated chamber.

Polishing the surface of concrete blocks appears to be impracticable. All those attempting it hitherto have failed because those trying to obtain a polish have failed to realize that unless certain conditions hold, no polish is possible. For instance, it is absolutely essential that the stone should consist of particles all of which are of equal hardness, if a good polish is to result. In the case of concrete, the cement and aggregate (sand, etc.) are often of very different hardnesses, and when attempts are made to polish it, a smeared appearance is obtained. This is especially the case when the polishing is begun before all the mass has been properly hardened.

When the best resultsare to be obtained, the stone should be coated with a magnesia fluate; this is followed with an alumina fluate. These fluates produce a surface of sufficient thickness and hardness to enable a good polish to be obtained.

Grading Concrete Bricks and Blocks. Manufacturers have a tendency to consider every brick made at their plant as of No. 1 quality, and very little grading of the bricks has been attempted. As a matter of fact, a plant will usually produce three grades of building material. To No. 1 would be long perfect bricks, clean moulded, with smooth surface, sharp edges and clean corners. The No. 2 would be bricks having four perfect surfaces, but with slight defects in the top and bottom bearing planes. The No. 2 bricks so graded will appear just as good in a wall as the No. 1, but where imperfections are to be found in the material, it is only proper that this distinction should be made. The No. 3 grade should be bricks which have slight defects in the corners and edges, as well as any other part and really these are the grade to be called "common" bricks.

When a concrete brick has a flaw amounting to a cubic inch of the material broken away, or if the brick is broken into two parts, it should be thrown away. It is impossible to manufacture a large number without having some of them imperfectly

* Readers who wish for fuller details will find them in "Cement, Concrete and Bricks," by Alfred B. Searle (Constable & Co., London).

moulded, insufficiently tamped or pressed, imperfectly hardened or damaged by careless handling.

In the clay brick business sometimes a whole kiln containing between 10,000 to 100,000 bricks is lost entirely by some accidental disturbance in supplying the heat necessary to burn the bricks, and even under the best conditions there is fully 5 per cent. of the bricks which are unsaleable and represent a total loss. This cannot occur with concrete bricks.

The proper grading of concrete bricks has not been given the attention it deserves. The percentage of unsaleable bricks is extremely low, and whilst it varies in different works, and the author is not prepared to give more than a rough figure, yet his observations in various countries show that about 25 per cent. of all the bricks manufactured might be picked out and called No. 1. These No. 1's are perfect bricks in every respect ; exactly uniform as to colour and if sorted out by themselves should bring a much higher price than any concrete brick has yet been sold for in this country, and what is more, the purchasers would probably be glad to pay the advanced price for this selection.

The No. 2 bricks would represent something like 55 to 65 per cent. of all the bricks manufactured and, in selecting them, only a slight variation as to colour should be permitted, for as the principal output of the plant is represented by this grade, they should be of such a character as to reflect credit upon the industry by producing walls which are uniform and smooth in appearance when completed.

The No. 3's, or common concrete bricks, may amount to 15 per cent., much depending on the care with which the bricks are handled; they are only used for inside walls or for work that is not exposed to the view. Discoloration matters little with these bricks nor do slight imperfections, such as bad corners and edges, disqualify them from this class, for the work in which they are to be used will never be seen, and the only qualities that will be required of them are strength and general uniformity as to size.

This system of grading would leave about 5 per cent. for culls, which are not fit for any use and should be discarded by the man who expects to build up a profitable business in the manufacture of concrete bricks. It is true that culls or broken bricks can be used for the aggregate material in making monolithic concrete for foundations or for filling in purposes in all the category of uses for which crushed rock has been used. A single labourer with a hammer can break up all the culls into proper sizes for such use at very small cost, and the cull pile itself could thus in most cases be sold for enough money to pay for its share of the expense of manufacturing bricks.

Notwithstanding the advantage to be gained by grading the bricks and selling at appropriate prices for each grade, the author knows only one manufacturer of concrete bricks who grades his product ; yet to omit to do this is one of the things that hinder an advance in the industry.

CHAPTER IX

ARTIFICIAL STONES

WHEN blocks of very large size are required, it is customary to regard them as being made of artificial stone. Many of the artificial stones for which Letters Patent have been obtained are really concretes and are made by methods which are identical in principle with those described in the previous chapter, though differing in minor details. *Stuart's Granolithic Stone, Globe Granite, Ward's Synthetic Stone,* and several others are of this class. Their value is solely dependent on the care and skill exercised in their production.

Basaltine Stone differs from the others in the use of basalt chippings for the aggregate, and the addition of finely-ground trass as well as Portland cement. The trass combines with the lime set free when the cement hardens (p. 101), forming a fresh cement and rendering the concrete more impervious than would otherwise be the case.

Some artificial stones are concretes which have been subjected to a subsequent process intended to harden them, *Victoria Stone, Imperial Stone, Empire Stone, Indurated Stone,* etc., being of this nature. Blocks of Victoria Stone are made, as described in the previous chapter, from aggregate which are chiefly composed of granite or other natural stones, and Portland cement. They are then immersed in a solution of water-glass (sodium silicate) where they remain for a fortnight or more. The sodium silicate is absorbed and on removing the blocks from the solution the silicate gradually hardens and fills up the pores near the surface of the block. Those in the interior are seldom affected by the immersion in the silicate solution.

Imperial Stone is made of aggregate and cement, and is subjected to the action of steam to increase the rate of hardening. After one day's treatment the blocks are immersed in a solution of water-glass for three days and are then slaked in the open air for six months or more before being used.

Ransome's Stone is also a silicated stone, but made without the use of concrete (*see* p. 3).

Ford's Stone is simply a lime-sand product made by ramming a mixture of 92 to 95 parts of fine sand with 5 to 8 parts of lime in the dry state into specially constructed moulds. These moulds are of steel, lined with copper, both shells being perforated. After being filled, the mould is connected to a vacuum pump and the air is exhausted. Superheated steam at a pressure of 120 lb. per square inch is then admitted into the vacuum, and it gradually hydrates the lime and forms the complex silicious bond which is characteristic of lime-sand products. The only object of hydrating the lime in this manner instead of previous to the material being placed in a mould, is that it would be very difficult to build a press of sufficient power, whereas, by using the force exerted by the hydrating lime, ample pressure for consolidating the material may be obtained.

The product is precisely similar to lime-sand blocks made in a press, as described in Chap. V, and the method there outlined is cheaper for blocks measuring less than 26 in. × 14 in. × 5 in. or equivalent volumes. When larger blocks are required Ford's process offers advantages, as perfectly homogeneous and flawless cubes up to 6 ft. each side can be made by it, such blocks having a crushing strength up to 600 tons per square foot and a porosity from 6 to 10 per cent. The hardness of the Ford blocks is regulated according to the purposes for which the stone is required, a hardness corresponding to that of the best free stone being generally adopted. In all its other properties this stone resembles those of lime-sand bricks described in Chap. X.

CHAPTER X

THE PHYSICAL PROPERTIES OF LIME-SAND BRICKS

To prevent misunderstanding, it should be noted that unless otherwise stated the remarks made in this Chapter apply equally to lime-sand, lime-clinker, and lime-slag bricks

THE physical properties of lime-sand bricks are of importance to the manufacturer, particularly when he is in competition with ordinary clay bricks.

APPEARANCE. Lime-sand bricks bear the closest possible resemblance to small blocks of very fine natural sandstones.

Surface. The surface of lime-sand bricks is smooth and of close texture, so that it is highly resistant to rain. It is largely self-cleaning, but any adherent soot or dirt may be removed by washing.

Texture. The texture of lime-sand bricks is best observed by studying the fracture. When two well-made lime-sand bricks are struck together they should give out a clear ringing sound. Dull-sounding bricks have been badly made, the fault being usually due to defective grading, insufficient mixing, or too short a time in the hardening chamber.

The *fracture, i.e.* the surface exposed when a lime-sand brick has been broken should show complete uniformity of texture combined with grains of considerable diversity of size cemented together by an amorphous bond. Lime-sand bricks in which the grains are all uniform in size and shape are usually weak, but no well-made brick should show obviously isolated grains, fissures, or masses of binding material. In a perfect lime-sand brick, each grain of sand is coated with a film of cementing material, and the spaces between each size of grain are occupied by smaller grains, the coatings of the smallest grains of all being in close contact with each other.

The appearance of the fracture of a lime-sand brick under the microscope is that of a mass of irregular grains fastened together with a somewhat more opaque material. If an exceedingly thin and almost transparent piece of such a brick be examined with a microscope by means of polarized light it will be found that each grain of quartz can readily be distinguished from the cementing material, and the uniformity or otherwise of the bond can be studied. The grading of the material may also be studied in a very effective manner by the examination of extremely thin sections of brick under the microscope.

The clean fracture of lime-sand bricks greatly facilitates the work of the brick-layer and reduces the amount of waste in cut bricks.

Shape. Lime-sand bricks are exceptionally regular in shape and surface, so that with reasonable care every brick may be used for facing purposes. It is, however, desirable to keep a strict oversight, as the workmen can damage the bricks by careless handling before they have been hardened. The better average shape, as compared with clay bricks, is due to the absence of any burning process and other important risks of deformation.

Size. As lime-sand bricks undergo no appreciable shrinkage in manufacture, they can be relied upon for uniformity of size, whereas many clay bricks differ greatly in size on account of variations in shrinkage. The great uniformity of size increases the rate at which lime-sand bricks can be laid and lightens the labour of the bricklayer as well as producing a building of more uniform appearance.

Hardness. Lime-sand bricks, if well made, are somewhat harder than common building bricks, but not quite so hard as vitrified bricks. In testing hardness care must be taken to avoid *crushing* the material.

Owing to the mode of manufacture there is nothing in lime-sand bricks which is equivalent to "underburned" or "overburned" bricks. In the case of clay bricks complete uniformity of heating is seldom attained, and this necessitates a certain amount of sorting. This operation is seldom necessary in an ordinary well-managed works making lime-sand bricks; if it has to be done there is some fault in the manner in which the bricks are made.

Colour. Lime-sand bricks are usually white or grey, but various colours may be obtained by the addition of pigments such as ferric oxide. The range of colour produced by the use of pigments is limited to reds, yellows, blues, and black. Red and yellow can only be used as faint tints, as to use them in quantities exceeding 5 per cent. by weight impairs the strength of the bricks and is too costly. Blue shades are obtained by the use of a little lampblack, and black by the use of larger quantities. The addition of pigments, unless extremely thorough mixing is used, will cause a variation in the colour of the bricks. The great difficulty, however, is the variation in colour between the different batches, due to a slight error in proportioning, the variation in the quality of the pigments, or the treatment during setting and hardening. Freshly pressed bricks kept in a hot dry place will have a lighter shade than those kept in a wet, damp place, even if all other conditions of manufacture are identical.* Where the colour is obtained from the aggregate, variation is due to a variable distribution through the mass. Most architects prefer the natural colour of the bricks.

The impurities in the sand used in the manufacture have an important influence in determining the colour of the finished brick, though the latter cannot be predicted from the colour of the raw sand.

The colour is more uniform than that of clay bricks, and there are no "accidental" variations in colour due to the use of a kiln.

When porous lime-sand bricks are wet they have an unpleasantly dirty grey

* Natural sandstone has the same characteristic.

colour and appear to contain much more water than is actually the case. On drying, the original colour of the bricks returns. This makes some architects regard them unfavourably as compared with what they regard as the picturesque aspect of an old building constructed of bricks made of red-burning clay.

Strength. The strength of lime-sand bricks is determined :

(*a*) By measuring the weight per square inch (or square foot) needed to crush them. This is termed the *ultimate compressive strength* or the *crushing* strength.

(*b*) By measuring the *modulus of rupture.*

Each firm making lime-sand bricks should have a machine for making one or other of these tests and should use it regularly, as it is the best means of controlling the quality of the output.

Where facilities for determining the crushing strength of bricks cannot well be afforded in the brickworks, it is desirable to have the tests made by an independent testing firm, whose certificate will be accepted by purchasers far more readily than if it were from the seller only.

The *crushing strength* is usually determined in Great Britain when the brick is in the same position as in a wall, a piece of stout millboard being placed above and below it so as to secure a good bedding. If the brick is hollow on one or both sides these should be filled up with plaster of Paris so that a perfectly flat surface is obtained; otherwise the results will be unreliable. The brick so prepared is placed in a crushing machine and the number of pounds pressure required to crush it is carefully noted. At least three bricks should be tested so as to obtain an average result. The pressure required divided by the area to which it has been applied (length of brick multiplied by the width, both in inches) will give the pressure in pounds per square inch.

Some people prefer to stand the brick on its end when testing it.

On the Continent, the bricks are broken into two pieces and these are fastened together with plaster of Paris so as to form a rough cube, which is then placed in the machine and tested as described.

Each of these positions in the crushing machine gives a different figure for the crushing strength, so that in reporting the results of such tests the position of the bricks must be stated; otherwise a difference of 30 per cent. may be observed. Thus, if a brick, tested as it is in this country, namely, with the entire area of the brick, shows a strength of 4500 lb. to the square inch, by cutting it in two and testing it as they do in Germany, the apparent strength would be reduced about 1350 lb. Hence in comparing the strength of bricks made in Germany with those made in this country, the difference in the method of testing should be taken into account.

E. Leduc, in "Essais Sur le Silico-Calcaire," uses a round sample of lime-sand brick in arriving at crushing strength. His rule is to use a cylinder, the height of which is exactly equal to the diameter, and he goes to considerable trouble to obtain this condition.

The crushing strength of good lime-sand bricks laid flat and tested when three days old will usually be within the following limits :

CRUSHING STRENGTH

	lbs. per sq. in.	tons per sq. ft.
Non-Plastic Bricks :		
Ordinary lime-sand bricks	2,200 to 3,000	140 to 193
Best quality lime-sand bricks	4,500 „ 9,000	290 „ 578
Lime-sand bricks for paving	8,500 „ 9,500	546 „ 610
Lime-clinker bricks	4,000 „ 6,000	257 „ 385
Lime slag bricks	5,270 „ 6,200	340 „ 400
Clay bricks :		
Best London stock bricks	1,600 to 2,800	103 to 180
Common London stock bricks	1,240 „ 1,865	80 „ 120
Fareham red bricks	1,550 „ 1,865	100 „ 120
Fletton bricks (semi-dry process)	2,620 „ 3,720	169 „ 239
Suffolk White bricks (Gault)	2,100 „ 2,870	130 „ 185
Staffordshire blue bricks	2,130 „ 7,200	137 „ 464
South Yorkshire bricks (stiff-plastic process)	2,330 „ 2,890	150 „ 250
Artificial stones :		
Ford's silicate of lime	9,330 to 10,888	600 to 700
Ransome's stone	7,000 „ 9,950	450 „ 640
Stuart's granolithic stone	7,777 „ 8,700	500 „ 560
Victoria stone	6,450 „ 8,330	415 „ 550
Concrete	1,555 „ 3,110	100 „ 200

It is well known that lime-sand bricks improve with age, due to the further combination of the lime and aggregate, and the absorption of carbonic acid from the atmosphere, converting any uncombined lime into carbonate. Specimens which have been made for five years have been found to have a crushing strength of 8000 lb. per square inch.

The resistance to crushing forms one of the chief means whereby the value of lime-sand bricks are tested. In this country there is, as yet, no general standard, but in Germany the *minimum* crushing strength permissible is 140 kilos per square centimetre, or about 2000 lb. per square inch, or 128 tons per square foot. This result can only be regarded as a minimum for legal purposes, for it is quite easy with most British sands and a good quality of lime to produce far stronger bricks.

No manufacturer of lime-sand bricks who cares for his reputation will sell bricks with a crushing strength below 2000 lb. per square inch.

It should be observed that the makers of clay bricks are seldom in a position to *guarantee* that all bricks sold by them have a minimum specified crushing strength.

This is due to the unavoidable variations in the clay or shale used and to the different degrees of heating to which clay bricks are subjected in burning. To the

FIG. 62. Villa Built of Lime-Sand Bricks
Courtesy of H. Alexander & Co. Ltd.

manufacturer of lime-sand bricks such a guarantee offers no difficulty. The importance of such a guarantee cannot be over-rated.

Brickmakers have usually worked under the impression that each man should be a rule unto himself, but since the introduction of new materials for brickmaking it has become necessary to devise some standard by means of which bricks made of slag, clinker, sand, cement, and other substances may be compared to one another and to bricks made of clay. Until recently bricks were simply bricks and nothing else, and it is, therefore, a matter of great importance to all concerned if any method of standardization be introduced into brickmaking. Firms who manufacture bricks from materials other than clay are particularly interested in this question, for upon it more than upon any other basis, are they able to found logical arguments in favour of their own goods.

Thus, the first man to test bricks made with new materials and to compare his results with tests on clay bricks, found a strong argument, and when he suggested in a paper before a prominent gathering of engineers that a good brick should have a minimum crushing strength of 500 lb. per square inch, he did better than he knew. Architects and builders were not slow to take up this suggestion ; many bricks were soon found which did not come up to the required standard and their sales were accordingly limited. More recently the compression figure has been raised to 2000 lb. per square inch, and this seems to meet most requirements.

It is important to point out this necessity for some definite physical test, as otherwise it is almost impossible to value lime-sand bricks at their full worth, or to compare them accurately with other kinds of bricks. It is the more necessary, as lime-sand bricks have been decried on all sides, not so much because of any inherent defects, as on account of their being a new and influential competitor to the ordinary brickmaker.

It is estimated that the crushing strength of cement concrete is ninety tons per square foot, but the safe working load very commonly adopted in building construction by architects and engineers for cement concrete, is seven tons per square foot, which allows a very large margin of safety. From these figures it is obvious that lime-sand bricks, with a crushing strain of 150 to 250 tons per square foot, are a better building material than cement concrete.

As the strength of the bricks is notably reduced when they have been saturated with water or after repeated freezings and thawings in a moist atmosphere, it is obviously desirable to make three crushing tests : (*a*) of the dry brick ; (*b*) of the brick saturated with water ; and (*c*) of bricks which have been repeatedly frozen and thawed in an ice store.

The exposure to frost should not be less than twenty-four hours each time, and the thawing is best accomplished by placing the bricks in a warm room. If a severer test is required, the bricks may be thawed by placing them in warm water, the temperature of which is maintained by blowing steam into it.

Crushing tests on bricks which have been frozen should be practically the same as those on the unfrozen bricks, but if the process of freezing and thawing is frequently repeated lower results will be obtained. This must not be understood to mean that lime-sand bricks deteriorate in frosty weather, as in actual use they have been found to stand frosts quite as well as any other bricks (*see* p. 118).

Sound bricks which have been frozen and thawed twenty times should not lose more than one-third their original compression resistance.

The crushing strength of lime-sand bricks is largely dependent on the details of manufacture being properly carried out. So far as variations in the raw materials are concerned, it will usually be found :

(*a*) That the less water required to produce a paste of a given consistency, the higher will be the strength developed by the sand.

(*b*) That the coarser the sand, other things being equal, the greater will be the strength developed.

(*c*) That the higher the silica content, other things being equal, the greater will be the strength developed.

(*d*) That where it is necessary to use sands of poor quality, temporary low strength can usually be overcome by using a dryer paste.

(*e*) That the loss of strength is usually temporary, and unless there is some serious error in manufacture a sufficient strength will be reached in course of time.

Modulus of Rupture. This is sometimes termed the *Transverse Test.* It is made by placing a brick, flat side down, on two knife-edge supports placed 8 in. apart, the load being applied centrally between the supports, through another knife edge. The load is increased steadily until the brick breaks, the load required for this purpose being then noted and the modulus of rupture calculated according to the formula $R = \frac{3WL}{2bd^2}$ where W is the load applied at failure of specimen, L is the distance between supports, b is the breadth of the specimen, and d is the depth of the specimen.

It should be understood that the "knife edges" are really triangular bars, of convenient size, the top of the triangular section forming the "knife edge." This "edge" may be slightly rounded if desired so as to reduce the cutting action of the bars.

The modulus of rupture should average 450 lb. per square inch, and should, in no case fall below 350 lb. per square inch.

The value of this test for concrete—under the title of Emperger's test—is rapidly gaining in popularity, especially on the Continent. It is much easier to carry out than a crushing test, but is thought by some architects and engineers to be less informative, the objection being that bricks are usually bedded and are not used as beams, as in this test.

Porosity. If walls are to be kept dry internally, it is desirable that the bricks used in their construction shall possess some amount of porosity, but they must not be too permeable to water. Care is therefore necessary in order to distinguish between the *porosity* and the *permeability* of bricks.

If a brick is placed in a basin of water, some air in the pores or voids of the brick will be displaced by the water, and the brick will become heavier in consequence of the water absorbed.

The usual method of testing the porosity of bricks is to weigh them accurately, partly immerse them in water for several hours, and then to immerse them completely all night. The object of the partial immersion is to facilitate the liberation of the air. In the morning the bricks are lifted out of the water, wiped rapidly with a cloth to remove the surplus water, and are then re-weighed. The increase in weight is that of the water absorbed by the pores of the bricks. This increase is multiplied by 100 and divided by the weight of the bricks so as to give the percentage (by weight) of water absorbed.

There are several advantages in calculating the volume of water absorbed per unit of volume of brick, but this is seldom reported.

The percentage (by weight) of water absorbed by the bricks tested in the foregoing manner is shown in the following figures :

WATER ABSORBED

	Per cent. by weight
Non-Plastic bricks :	
Ordinary lime-sand bricks	8 to 12
Best quality lime-sand bricks	3 „ 9
Lime-sand bricks for paving	0 „ 2
Lime-clinker bricks	3 „ 10
Lime-slag bricks	3 „ 15
Clay bricks :	
Common bricks	10 „ 25
Facing bricks	5 „ 15
Medium engineering bricks	1 „ 5
Best engineering bricks	Below 1

The method of testing described above, though usually adopted, is by no means as accurate as is commonly supposed. More accurate results are obtained if the brick is first placed in a glass vessel and the air is exhausted from the latter. On water being admitted it enters more completely into the pores of the brick than if the latter were merely to be immersed in water. Some pores, being sealed, their presence cannot be detected without crushing the bricks to powder.

The porosity of lime-sand bricks is largely dependent on the grading of the material and on the care taken in the details of the manufacture. Excessively porous bricks have usually been made of badly graded material, but the defect is sometimes due to inefficient pressing.

The colour of lime-sand bricks is changed temporarily when they are wet, but as they again become dry their original colour is restored.

Permeability. A brick may not show a high percentage of absorption, but it may be unsatisfactory on account of the facility with which it allows rain to permeate through it.

The permeability of a brick may be tested by measuring the quantity of water which penetrates through the brick in forty-eight hours, the brick having been saturated with water before the test is commenced.

In order to obtain comparable results, it is very necessary to use test-pieces of a standard size and to always use a tube of the same internal diameter, with water at a constant level within it. The usual diameter of the tube is 1 in. inside diameter, the water level inside being maintained at a height of 4 in. by some simple automatic feed of the Mariott bottle type. The sample to be tested, with the tube attached, is immersed in water until saturated, is then removed, wiped carefully, and the tube is filled with water and the brick stood on two knife edges. The water collected in a vessel placed below the sample is measured at the end of forty-eight hours. Its amount may vary from a single drop to half a pint with a sound brick. A brick with a flaw in it may permit the water to flow through as rapidly as it can be supplied. The variations are so great that no accepted standard of permeability has been reached, and an average cannot be stated with reasonable accuracy until many more tests have been made. Bricks from the same works, made under apparently identical conditions, often show remarkable variations in permeability. If a standard is to be fixed it will probably be to the effect that a brick must not, under the conditions described above, permit more than 3 oz. of water to pass through it in forty-eight hours.

Permeability is sometimes measured by standing the bricks on end in a shallow tray of water and observing the height to which the water rises by capillary action. This is a very misleading test and should not be used for this purpose.

Low permeability for water with high permeability for air is brought about by numerous and very fine pores in the bricks. Larger pores will permit water to permeate too readily. These exceedingly fine pores are very important as they enable the walls to " breathe properly," *i.e.* they permit a circulation of air through the building. Houses whose walls do not possess this permeability to air, but are made of impervious engineering bricks, are uncomfortable and unhealthy, with a great tendency to dampness owing to any moisture which enters the rooms being unable to escape in the form of vapour through the walls.

It should be observed that there is no noteworthy difference in permeability between lime-sand bricks and bricks made of clay.

Rate of Drying after Rain. The rapidity with which a brick dries after exposure to rain depends largely on its porosity and permeability. Bricks with coarse pores allow so much rain to enter that they do not dry readily. If the pores are so fine that the rain does not penetrate deeply into the bricks and yet permit air to percolate freely through them, the bricks will dry rapidly.

There is no essential difference in the rate of drying after rain between bricks made of clay and of lime-sand, but the physical properties of the bricks must be similar. No accurate comparison is possible where they are widely different.

Relative Weight. The relative weight of walls built of lime-sand bricks and of ordinary clay bricks are almost identical, though a lime-sand wall is about 10 per cent. lighter than a similar wall of engineering bricks made of a clay which is vitrified in the kiln.

Density. The term density is often used in the sense of being the opposite of porosity, those bricks being termed " dense " which possess a close texture devoid of fissures and apparent pores. A more accurate use of the term " density " recognizes two kinds of density; the true density (see *specific gravity*) and the apparent density. The *apparent density* of a brick is the ratio of the weight of a unit volume of the material, including the pores to the weight of an equal volume of water. Thus, if a brick measures 9 in. × 4½ in. × 3 in. and weighs 9 lb., its volume (including pores) will be 121½ cb. in. and 1 cb. ft. (or 1728 cub. in.), will weigh exactly 2048 oz. As 1 cb. ft. of water weighs 1000 oz. the apparent density of such a brick is 2.048.

It is usually more convenient and more accurate to use the metric system of weights and measures, but this does not otherwise affect the result.

Where an accurate result is required it is necessary to measure the volume of the brick in a volumenometer, the brick having first been dipped in paraffin-wax or other suitable material so as to seal all the pores.

The apparent density depends on the compactness with which the particles have been pressed together and so is an indicator of the skill used in manufacture, and is particularly useful as a measure of the accuracy of the grading and pressing. In conjunction with the water absorbtion (see *Porosity*, p. 111), it forms one of the best means of controlling the manufacture.

Specific Gravity. The apparent density, as already explained, includes the pores in the brick, but the *true density* or specific gravity relates exclusively to the solid material of which the bricks are composed. It is the ratio of the weight of a unit volume of the solid material of the brick to the weight of an equal volume of water.

In order to determine this ratio, it is necessary to eliminate the pores, and this is most readily accomplished by grinding the sample to a fine powder and measuring the volume of this powder in a pycnometer, in the manner described in many standard text-books on physics.

The specific gravity of lime-sand, lime-clinker, and lime-slag bricks depends entirely on the nature of the raw materials used, but does not differ greatly from 2.56. This is not appreciably different from the specific gravity of clay bricks.

Elasticity. Well-made lime-sand bricks have a slightly higher modulus of elasticity than is possessed by the best natural sandstones. This is due to a slightly larger proportion of bond and its better distribution through the material. The importance of this lies in the lesser brittleness of the lime-sand bricks and their greater ability to stand temporary stress without cracking.

Heat conductivity. The rate at which lime-sand or similar bricks conduct and transmit heat has been found to be so similar to that of other bricks that no appreciable difference has been observed. Hence, the amount of fuel required to heat a building, the walls of which are of lime-sand bricks, appears to be exactly the same as that for a similar building constructed of ordinary bricks.

Adhesion of Mortar. It has been conclusively proved by several quite independent investigators, and it is a matter of common knowledge to those accustomed to bricks made of non-plastic materials, that mortar will adhere as well to lime, sand, lime-clinker, or lime-slag bricks as to bricks made of clay. There was a considerable amount of discussion on this subject some years ago—particularly in Germany—but as soon as sufficiently extensive tests were made, the equality and, in some cases, the superiority of lime-sand bricks were fully established.

The following test was made at the request of Messrs. H. Alexander & Co. Ltd., and shows the comparison between average lime-sand bricks and average clay bricks made by the stiff-plastic process.

Three bricks were fastened together with mortar as shown in Fig. 63. The average thickness of the joint at each side the centre brick was $\frac{5}{16}$ in. The average surface of contact was 44 sq. in.

Mortar A was composed of one measure of lime putty and three measures of sand.

Mortar B was composed of two measures of lime, one of cement, and eight of sand.

The test-pieces were placed in the open air for three months and were then compressed in the direction of the arrows, with the results shown in the Table on p. 116.

In short, it is quite erroneous to suppose that mortar will not adhere to lime-sand bricks as well as to bricks made of clay, and statements to the contrary will not bear a rigid investigation.

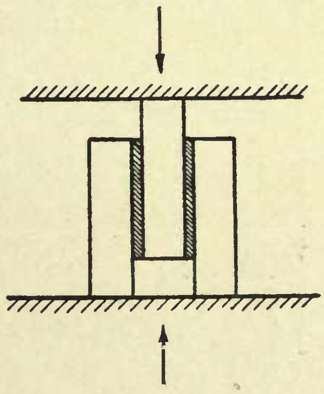


FIG. 63. Testing Adhesion of Mortar

Hardening of Mortar. It was, at one time, alleged that mortar does not harden well when used in connection with lime-sand bricks. Such an allegation is quite untrue and all the best experimental evidence points in precisely the opposite direction.

The whole subject of the hardening of mortar is too complex to be discussed in the present small volume, and it is here sufficient to state that no builder need have the slightest fear with regard to the hardening of mortar on lime-sand and similar bricks.*

What has led to confusion in some minds on this subject is the fact that many people have expressed opinions without making any tests, and some experimenters have drawn wrong conclusions, because they endeavour to compare bricks of widely

* It is treated in considerable detail in "A Manual for Masons," by J. A. van der Kloes and A. B. Searle (J. & A. Churchill, London, 1913).

different texture. For a comparison to be at all accurate the bricks must have some similarity in texture. For instance, it is useless to compare a brick with a dense surface with one of an open and porous nature. Moreover, the whole subject of hardening is so complex that anyone without a full knowledge of it may easily draw entirely wrong conclusions from his experiments.

In an elaborate test made by the Royal Testing Station at Gross Lichterfelde and reported in the *Tonindustrie Zeitung*, 1912, p. 541, it was found that the mortar was equally well hardened with lime-sand as with other bricks and that no difference

Comparative Tests of the Adhesion of Mortar to Clay Bricks and Lime-Sand Bricks (*see* Fig. 63)

Test No.	Clay Bricks Pressure in lbs.		Lime-Sand Bricks Pressure in lbs.	
	Mortar A	Mortar B	Mortar A	Mortar B
1	264*	2530†	‡	3750†
2	22*	3180*	1120†	5530*
3	22*	2165*	970†	3450†
4	55*	2135†	374†	4480*
5	66*	1210*	‡	3680†
6	99*	1825†	1055†	4820†
7	44*	1100*	680†	4170†
8	110*	1088*	914†	3688†
Average Pressure . .	85	1904	850	4196
Average shearing resistance in lbs. per sq. in. .	1.9	43.0	19.3	93.1

* The mortar joint cracked and broke. † The mortar parted from the bricks.
‡ The test-piece broke previous to the pressure being applied.

in the adhesion of the mortar could be found. In short, all observations made on properly built walls of sufficient size and left for a sufficiently long time to make a fair test, have shown that mortar adheres to lime-sand and similar bricks and hardens quite as well as when bricks made of clay are used.

Refractoriness. This term is used to indicate the resistance of a material to prolonged heating at a high temperature. Thus, firebricks are valued because of their greater refractoriness than building bricks. Unfortunately, the term is used somewhat loosely, but among the better informed engineers specializing in furnace kilns and retorts, three grades of refractoriness are recognized.

(1) Those materials which show no signs of fusion when heated slowly up to a temperature which causes the bending of Seger Cone 30 (1670° C. or 3038° F.).

(2) Those materials which show no signs of fusion when heated slowly up to a temperature which causes the bending of Seger Cone 26 (1580° C. or 2876° F.).

(3) Those materials which show signs of fusion below a temperature which

causes the bending of Seger Cone 26 (1580° C. or 2876° F.), but which are sufficiently refractory for the particular purpose for which they are required. This grade of firebrick is chiefly used for domestic purposes and as a backing for more refractory bricks.

The refractoriness of lime-sand and simlar bricks depends on the fusibility of the aggregate and on the proportion and distribution of the lime present. If the aggregate consists of a very pure quartzose sand, and there is not more than 3 per cent. of lime present, the bricks will have sufficient refractoriness to be classed as No. 1 grade, but this requires the most careful selection of materials. Where this is possible, the highest grade of *silica firebricks* can be manufactured like lime-sand bricks, but the bricks, after being hardened, require to be burned in specially constructed kilns, in which they should be fired to a temperature of not less than 1500° C. or 2732° F. This method of manufacture has the advantage of producing bricks of much better shape than the ganister or silica firebricks usually employed for lining furnaces. The allegation that bricks which have been made in a power-driven press will spall and flake too easily to be satisfactory is only true where the grading is defective or where the press is wrongly used. The fact that this method is regularly used in several of the most important works making silica firebricks is a sufficient proof of its value and practicability. The machine-pressed bricks last longer because their more accurate shape enables them to be laid better.

Where a less pure sand is used, lime-sand bricks can be made satisfactorily in place of firebricks of No. 2 or No. 3 grade, though for No. 2 grade they may require to be burned in kilns, but at a temperature of (say) 1300° C. or 2372° F. before they can be used. This burning is necessary to obviate the troubles due to expansion which would otherwise result when the bricks were heated in the furnace. For replacing No. 3 grade firebricks, any lime-sand brick may be used, and it is correct to state that any properly made lime-sand brick can be used with confidence as a substitute for the *average* No. 3. quality of firebricks.

Lime-clinker and lime-slag bricks are not so refractory as furnace bricks made of silica or ganister, though they do not usually show signs of fusion at a temperature below that at which some low-grade fireclays begin to lose their shape.

Fire Resistance. The ability to withstand the devastating influence of a conflagration is an extremely important requisite in modern building materials. This is quite different from what has been described above as the refractoriness of a material. For instance, steel will melt at a temperature considerably below that at which even a No. 2 grade firebrick begins to lose shape, yet doors covered with steel have been proved to be amply resistant to conflagration.

Thus, in order that bricks may be fire-resistant, in the sense in which this term is ordinarily used, it is not necessary that they should have an extraordinarily high melting-point, but that they should offer a sufficient resistance to the flames and heat of a conflagration until the fire can either be extinguished or allowed to burn itself out. Fire-resistance is usually tested by building a structure of the bricks to be examined, filling it with wood soaked in oil and setting the latter on fire. When the fire has reached its greatest heat, it is rapidly extinguished by water applied through hose by a fire-brigade, and the bricks are examined to see how far they have suffered.

When subjected to such a test on a sufficiently large scale, and in actual conflagrations of buildings in which they have been used, lime-sand and similar bricks have proved completely satisfactory and in a number of instances have stood better than common building bricks made of clay.

Generally speaking, lime-sand and similar bricks are not so sensitive to sudden changes in temperature as are most bricks made of clay, and the latter crack and "fly" much more easily than do lime-sand bricks. This has been repeatedly observed in buildings in which both clay and lime-sand bricks have been used.

A test which is based on a misunderstanding of what is required, consists in placing a few lime-sand bricks in an ordinary brick kiln along with unburned clay bricks. When subjected to such a treatment, the lime-sand bricks will become dull and soft, and may even fall to pieces, for the combined action of the steam and heat decomposes them. If pieces of mortar were similarly treated they would fall to powder.

In 1906 this test formed the basis of an action in the law courts in Germany, and it was then decided * that such a test is "unscientific and false, and the decomposition of a lime-sand brick under such conditions is no indication whatever that a structure built of lime-sand bricks would suffer more in a conflagration than a similar structure of clay bricks." On the contrary, the greater resistance to heat of bricks made of sand, slag, or clinker results in their being fully as valuable as—and in some cases more so than—bricks made of clay.

Frost Resistance. In this and many other countries it is important that all bricks and building stones should be highly resistant to the action of frost. So long as the bricks remain dry, the frost has no action on them, and it is only when they have been wetted that the risk of damage arises.

This is due to the fact that when water freezes and is converted into ice, it expands appreciably, and if the pressure on the surrounding material is greater than the latter can stand, serious damage may result. If, on the contrary, the particles of which the bricks are made are so strongly cemented together that they can withstand the expansive force exerted by the water at the moment it freezes, no harm can result. Hence, the resistance of a brick to the action of frost depends on the strength of the bond uniting the particles.

Lime-sand bricks which have been soaked in water, when examined by direct tests, have the same resistance to freezing as well-burned clay bricks of a similar porosity, and practical experience in trying climates confirms this statement. The fact that about 1,000,000,000 lime-sand bricks are used each year in Germany—

* *Tonindustrie Zeitung*, 1906, pp. 1025 and 1205.

where the climate is very severe in winter—is sufficient evidence of their durability with respect to frost.

For the following test ten bricks were made thoroughly wet and were then frozen by maintaining them at − 11° C. for four hours, after which they were thawed by soaking them in water at 15° C. for three hours. This alternate freezing and thawing was repeated twenty-five times.

Ultimate Crushing Strength of Lime-Sand Bricks

No.	Dry Bricks	Bricks Saturated with Water, but not Frozen	Bricks Tested after Twenty-five Freezings
	lb.	lb.	lb.
1	14,280	13,380	11,580
2	13,380	12,360	13,610
3	13,270	12,250	10,440
4	14,290	13,610	13,950
5	14,060	12,810	11,350
6	12,020	12,700	11,000
7	14,510	13,160	10,670
8	14,060	13,390	12,920
9	13,150	13,950	11,110
10	13,720	12,250	11,350
Average . . .	13,674	12,986	11,798
Average (lb. per sq. ft.)	2,925	2,783	2,525

The bricks had an average porosity of 13.4 per cent. by weight.

It should be observed that although there is an average loss in strength due to repeated freezings, yet this loss is no greater than the difference in the strength of the frozen bricks. Nor do lime-sand bricks show any greater loss on repeated freezings than do bricks made of clay. Indeed, few clay building bricks picked at random will stand this freezing test so well as an equal number of ordinary lime-sand bricks. The variations in clay bricks are much greater, and the average is, therefore, poorer. This is due to the inevitable variations in the burning of clay bricks.

Resistance to Weather. The effect of weather on bricks is chiefly observable after a period of wet weather followed by frost (*see* "Resistance to Freezing," *supra*). In country districts no other climatic influences are of much importance, but in towns and manufacturing centres the action of acid vapours and soot must be considered. These do not corrode lime-sand and similar bricks any more than they do natural stones of similar composition and porosity.

Table of Comparison of Properties of Various Kinds of Bricks

	Lime-sand Bricks	Clinker Bricks	Slag Bricks	Cement-sand Bricks	Red Bricks of Plastic Clay
Appearance .	Like natural sandstone	Light grey	Light grey	Like natural sandstone	Characteristic
Texture. .	do.	Like natural sandstone	Like natural sandstone	do.	do.
Shape . .	Accurate	Accurate	Accurate	Fairly accurate	Liable to twist in drying and burning
Size . .	do.	do.	do.	do.	Varies with shrinkage in drying and burning
Colour . .	Very uniform	Uniform	Uniform	Very uniform	Variable. Seldom two bricks exactly alike
Crushing Strength. Tons per sq. ft. .	140 to 600	257 to 385	340 to 400	100 to 200	80 to 250
Porosity % .	3 to 12	3 to 10	3 to 15	3 to 10	5 to 25
Permeability .	As red clay bricks	As red clay bricks	As red clay bricks	As red clay bricks	—
Rate of drying	do.	do.	do.	do.	—
Relative weight	do.	do.	do.	do.	—
Density .	do.	do.	do.	do.	—
Adhesion of mortar. .	do.	do.	do.	do.	—
Hardening of mortar .	do.	do.	do.	do.	—
Refractoriness in Seger cones	18 to 32	10 to 20	12 to 22	18 to 30	Under 18. Firebricks 26 to 32
Fire resistance	Better than red clay bricks	As red clay bricks	Rather better than red clay bricks	Often better than red clay bricks	—
Frost resistance	Rather better than red clay bricks	Rather better than red clay bricks	do.	Rather better than red clay bricks	—
Weather resistance	As red clay bricks	As red clay bricks	As red clay bricks	As red clay bricks	—
Time required for manufacture . .	1 day	1 day	1 day	1 month	20 to 90 days
Cost of manufacture .	16s.	15s.	15s.	1 month	18s.

The objection has sometimes been raised that lime-sand bricks soon become dirty, but careful observations have shown that they do not show the dirt any more readily than natural stones of similar colour, and they can, when desired, be cleaned by washing. The objection that lime-sand bricks have not so æsthetic an appearance as those of red-burning clays is purely a matter of individual opinion and its importance must be judged accordingly (p. 136).

Briefly, it may be stated that bricks properly made of lime-sand and similar materials are equally as durable as natural stones and as many clay bricks. Indeed, they are more durable than some clay bricks used for inside work and occasionally for exterior work in many parts of the country. The *best* bricks of clay or shale, made by a plastic or semi-plastic process and carefully burned so as to secure a sufficient amount of vitrified matter, are stronger and more durable than non-plastic bricks, but the cost of manufacture is too great for such clay—or shale—bricks to be used for other than facing purposes and for engineering work. Hence, such bricks do not compete with non-plastic bricks to any great extent, and a detailed comparison is, therefore, useless. The legitimate sphere of non-plastic bricks is for ordinary building purposes (as described in further detail in Chap. XIV), and if their use is confined to this they prove perfectly satisfactory.

It will almost invariably be found that the disadvantages and drawbacks which are alleged to attend the use of bricks made of clinker, slag, or sand, are based on badly made bricks. With bricks which have been properly made, no such drawbacks exist, though the industries concerned have suffered very severely from unfair criticism based on superficial observations of bricks which have been improperly made and ought never to have been used.

CHAPTER XI

THE PHYSICAL PROPERTIES OF CONCRETE BRICKS AND BLOCKS

BROADLY speaking the properties of concrete blocks and bricks are the same as those made from a similar aggregate, but with lime instead of Portland cement as the binding agent (*see* Chap. VIII).

Much misconception exists and many quite erroneous statements have been made by persons interested in clay bricks, terra-cotta, or natural stone. In fact there is still a large number of people who consider that cement bricks are exceedingly vulnerable to moisture after being placed in the wall, by reason of the fact that every shower of rain temporarily changes the colour of the exposed wall and makes it appear to be very wet. This is an illusion, for most well-made concrete bricks will not absorb as much water as a clay brick of equal quality when both are immersed, nor will a concrete brick wall absorb anything like the amount of rain as will many clay-brick walls. It requires only a very short period of time for the concrete brick wall to resume its natural grey colour, which proves that the moisture has never penetrated it to any great extent.

There is an æsthetic objection to concrete blocks and bricks which is met by the same arguments as apply to lime-aggregate blocks (p. 121), and some architects make much of the discoloration of concrete. This is due to the working out of the lime set free during the hardening of the cement. It may be avoided by using a little trass or brickdust in the aggregate.

This discoloration is not so noticeable in walls that have stood for a long time and have been repeatedly moistened and dried out, as it is the intrinsic cleanness of the cement brick that lays it open to this apparent objection. A wall constructed of concrete bricks is more impervious to moisture, has a greater crushing strength and will carry a greater transverse load than many clay bricks.

Perhaps there is no question that is asked more frequently in connection with concrete bricks than that with reference to their behaviour in the presence of heat, and what will become of them in a conflagration. The comparative tests which have been made all show that properly made concrete bricks will stand a fire as well as ordinary clay bricks other than engineering bricks, and will be superior to many common clay bricks. When tested for strength after being so superheated, there has been found little or no difference in the crushing, tensile, or transverse strength of well-made concrete bricks.

CHAPTER XII

DEFECTS

THE defects which are likely to arise in the manufacture of non-plastic bricks are not very numerous. With materials of a suitable nature, they are almost invariably due to (i) some unauthorized change in the method of treatment, (ii) to endeavours to hasten the manufacture unduly, or (iii) to an erroneous method of working, made in the endeavour to avoid the use of expensive plant. The following are the most important defects :

Absorbtion. If excessive, indicates imperfect grading of the material. The necessity of having the grains of suitable sizes has been shown in Chap. I (see also *Porosity*).

Excessive absorbtion may also be due to insufficient bond being present, as when too little lime is used, or if it is imperfectly distributed or does not harden properly.

The excessive absorbtion of some lime-sand bricks is sometimes made an objection to the use of this kind of brick. This is unfair, as it is only badly made bricks which have this defect.

Alligatoring is the term used to describe a series of cracks on the surface of bricks, blocks, and concrete, these cracks forming a network or pattern which is thought by some people to bear some resemblance to an alligator's skin. The defect is produced by the use of too much cement in the mixture of which the articles are made or with which they are covered.

Blisters are due to particles of quicklime becoming hydrated and swelling. Their presence indicates defective hydration of the lime.

Blotches of colour on the bricks are due to dirt falling on them, to faulty mixing or to unsuitable material (see *Discoloration* and *Spots*).

Blowing consists of small hollows caused by the lime being insufficiently slaked and imperfectly mixed. It thus appears as small spots or blotches on the surface of the bricks, and as the rain washes it out, the hollows or " blow-holes " are left. If similar masses of quicklime occur somewhat beneath the surface they will expand when slaked by atmospheric moisture, and may cause the bricks to spall, flake, or crack.

The remedy consists in fully hydrating the lime and in mixing the paste more thoroughly.

When a firm is troubled by " blown " or cracked or broken bricks, and cannot account for the cause of these defects, it is a good plan to pass about two pounds of the lime through a sieve having at least 80 holes per running inch, in order to see how much remains on the sieve after a gentle brushing of the material with a moderately soft brush. If more than a quarter of an ounce of material is too coarse to pass through the sieve, it is pretty certain that the lime has not been crushed sufficiently fine to hydrate properly, and it is this coarse lime which is probably the chief cause of the trouble. If hydrated lime is used this may be tested in a similar manner.

Bursting (see *Blowing* and *Cracks*).

Chipping or Spalling is sometimes due to the outer portion of the brick being made of a finer and less contractile material than the core. It may also be due to irregularity in the composition of the bricks. Some bricks are alleged to have spalled when they have merely been badly treated, and have received blows, or other results of careless handling.

Cracks in bricks are due to a variety of causes of which the most important are : (*a*) unsuitable materials ; (*b*) an excess of lime, especially if this is not properly hydrated (see *Blowing*) ; (*c*) defective pressing, the mould being badly filled with a material of unsuitable consistency, or the plunger of the press working badly ; (*d*) too rapid a hardening.

In the case of silica firebricks, cracks may be caused by improper treatment in the kilns and especially by too rapid a heating or cooling.

Lime dust, if allowed to dry on freshly pressed bricks, will sometimes produce fine hair cracks like spiders' webs. By taking care to keep the lime-bins away from the press, this form of cracking may be avoided.

Cracks which form a network on the surface of the bricks may be due to the steam having been turned on too suddenly in the hardening chamber ; this causes a difference in expansion of the outside and the inside of the bricks. If the steam is turned on gradually, no such cracks will be produced.

Crooked or *Twisted* bricks are invariably due to careless handling—usually when taking the bricks from the press. The defect is more pronounced if the bricks are made from too soft a paste.

Discoloration takes several forms, *e.g.* (*a*) the white "frost" which appears on bricks which have been repeatedly wetted and dried, and is due to soluble salts such as calcium sulphate, magnesium sulphate, calcium chloride, common salt, and any surplus lime, which are brought to the surface of the bricks as the water dries out of them. This "scum" or efflorescence does little or no harm, and may usually be washed away if it is considered to be unsightly.

(*b*) A discoloration due to free lime in the bricks makes them appear as though they had been whitewashed. It is due to insufficient steaming, imperfect grinding, or to excessive lime in the case of lime-aggregate bricks. In the case of concrete bricks it is unavoidable unless trass or brickdust is included in the aggregate.

(*c*) Only occurs with coloured bricks and is due to the colour being improperly mixed with the material. If coloured bricks are desired they should be made with special care to ensure a thorough mixing, and the colouring matter should be added to the sand and well mixed with it before the lime is added. It is desirable that the sand should be *dried* before mixing the colour with it. It is essential to obtain as perfect a mixture as possible if an uniform tint is to be obtained. If the bricks can be dried rapidly on the surface before they enter the autoclave the tint will usually be more uniform.

(*d*) Discoloration caused by water, containing iron or other colouring matter in solution, running over the bricks is seldom the fault of the manufacturer. Such discoloration can seldom be removed.

Dusting is due to unsuitable foreign material in the sand, too little bond in the mixture, bad mixing, too much time elapsing between mixing and pressing, insufficient hardening or the use of too much cement. One form of dusting is really scum *q.v.*, and is due to insoluble salts which come to the surface and are easily brushed off.

Efflorescence, or scum, is sometimes known as " wall white " (*see Discoloration*). It may be due to soluble salts which exist as impurities in the raw materials or to the bricks being stacked on ground made of or covered with ashes.

If sea-sand is used in the manufacture of the bricks it will, in all probability, cause the formation of a whitish scum. This is due to the salt dissolving in the water and condensed steam used in making the bricks and being left on the surface when this water dries out of the bricks. For this form of scum the only preventative is to use fresh-water sand, as it is almost impossible to wash sea-sand sufficiently free from salt.

The storage of the bricks on ashes or other material containing salts is the chief cause of scum in lime-sand bricks. If the ground is wetted with rain, the salt dissolves and the bricks draw up the solution by capillary action, and the salt is left on their surface as the bricks dry. It is, therefore, very important that bricks should never be stacked on ground made of ashes or other materials containing soluble salts.

In many slags there is a proportion of soluble salts which tend to spoil the bricks when allowed to harden naturally by appearing as efflorescence. This, in some cases, is accompanied by osmotic pressure, and the outer crust may then be forced away from the brick ; but the same effect does not happen when they are steamed, the steaming either turning the salts into a stable compound or driving them off.

Some destructor clinkers are particularly objectionable in this respect and have either to be treated to remove the scum-forming salts, or the clinker must be discarded if the appearance of the bricks is objectionable to the users. Sometimes the salts in the bricks may be made insoluble by means of barium carbonate.

Flakes on the surface of the bricks are usually due to the mould or press-box being corroded. The only remedy is to re-line it and so prevent more bricks being spoiled in the same way.

Holes and *Hollows* in the bricks are usually due to imperfect mixing, but they may also be caused by the lime not being properly hydrated (see *Blowing*).

Irregularity in the Size of the bricks is due to the moulds or press-boxes being worn and requiring to be re-lined, or to some fault in the construction of the moulds. If the consistency of the paste of which the bricks are made varies greatly this will also cause them to be irregular in size.

If the press is of a suitable kind it will have an arrangement whereby the size of the bricks can be regulated to allow for slight variations in consistency ; if this arrangement is out of order the bricks may be irregular in size.

Lamination, or the formation of layers or laminæ in the bricks, is due to imperfect delivery of the material into the press, especially if an almost dry mixture is used. With suitable presses and a mixture of normal consistency, no lamination should occur ; if it does so, the press should be overhauled by an expert, as lamination is too serious a defect for the brickmaker to attempt to put right without expert assistance.

Lumps, or projections on the surface of the bricks, are usually due to pieces of lime which lie just below the surface and have not been properly hydrated. In the hardening chamber the hydration is completed and the increased volume of the lime causes the swelling of the bricks at those places where the lime occurs.

Oiliness may be regarded as a form of discoloration. It is due to carelessness in oiling the machinery.

Peeling (see *Chipping*).

Pitting of the surface of the bricks is a defect which is primarily caused by insufficient hydration of some of the lime. It may be a sign that the mixing plant is out of order, but is more usually an indication that the length of time during which the material has been stored in a silo is too short. The remedy in such a case is obvious ; the material must be stored for a longer time before being pressed.

Popping is a term sometimes used instead of *Blowing* (p. 123).

Porosity, if excessive, is due to insufficient lime, insufficient hardening or defective grading. The true cause of excessive porosity is the absence of sufficient fine aggregate and bond ; careful grading of the aggregate (p. 7) will probably reduce the porosity.

Scum (see *Efflorescence*).

Soft or Weak Bricks may be due to the causes mentioned under *Weak Arrises*, but are chiefly due to insufficient pressure. In this connection it is interesting to note that bricks made on a vertical press are always weaker than those on a single mould rotary press, this difference being partly accounted for by the greater difficulty experienced in filling the mould of a vertical press so uniformly as that in a rotary table.

Another frequent cause of weak bricks is an improperly prepared material—possibly of unsuitable composition as well as imperfectly mixed—or to imperfect distribution of the lime so that only a portion of it is used as a bond. This cause of trouble is best avoided by grinding some of the sand with the unslaked lime in a ball or tube-mill as described in Method D (p. 65). If any colouring matter is to be used, it should be ground at the same time as the lime.

Insufficient hardening will also make bricks soft, as will too little finely divided lime. The general average of 6 per cent. of lime should not be reduced without special reasons, nor should the time of hardening be reduced below ten hours unless under skilled advice, based on the results of many tests of the materials. Care should also be taken that the steam in the hardening chamber is maintained at the requisite pressure. The pressure most suitable for a given material depends on its composition—the less lime present the greater the pressure and the longer the time of hardening—but the average lies between seven and fourteen atmospheres, or about 120 lb. per square inch.

Soft bricks may also be due to the bricks standing too long before entering the hardening chamber, especially if the air in the shed in which they are kept contains much carbon dioxide from fires, etc. The remedy then consists in taking the bricks to the hardening chamber immediately they come from the press (*see* Chap. VII).

Bricks made of sand, slag, or clinker are sometimes condemned because they are not as hard as those made of clay. This is a mistake as it will be found that they will resist crushing as well as most clay bricks and better than common clay bricks. It is not the hardness, but the compressive strength which should decide the value of bricks, for a weak brick may have a surface which is difficult to scratch with a knife, and a strong brick may appear to be quite soft by the same test.

Spots. If white, these are probably due to the lime being imperfectly mixed. When other methods of prevention fail or are impracticable, it is best to mix the lime with some sand, clinker, or slag as the case may be, *before* hydrating, or even to grind the lime and some of the aggregate together. Lime which is hydrated and moist is exceedingly difficult to mix properly with wet aggregate, and is a common cause of spots.

Streakiness is probably due to the same causes as *Spots* or *Discoloration.*

Sweating is usually due to the bricks being made of too wet a material or to their being insufficiently porous when finished. For the former, a dryer mixture will prove a remedy ; the latter indicates the need for a better grading.

Swelling. Bricks which, when finished, are too large, may have swelled during the hardening. This is usually due to the lime being imperfectly slaked, and is commonly a sign that too little water has been added during the mixing.

In several instances in the writer's experience it has proved cheaper to do away with the ordinary hydrating plant for the lime, and to crush the lime in an ordinary stone crusher, passing it then through a tube-mill in order to grind it to an impalpable powder, after which it is simply mixed with the sand and water in an open mixer, and then passed to the silo or storage bin. This treatment entirely cured both blowing and expansion, and although the works where it has been installed were formerly greatly troubled with cracked and shattered bricks, these are entirely unknown since employing an unhydrated lime and a storage bin, in which the mixed sand, lime and water are kept for about fifty hours before being finally mixed and moulded.

Unevenness is due to incomplete grading, insufficient mixing or to the press being worn. The remedy will depend on which of these are the cause, but is obvious if the bricks are carefully examined.

Warped bricks are caused by careless removal from the press—often aggravated by the use of too soft a material.

Weak arrises and corners are generally due to a defect in the press. They may be caused by the plunger not fitting into the box of the die with sufficient accuracy, to the absence of escapement for the surplus material, or to the design of the press being such that the pressure is incorrectly applied.

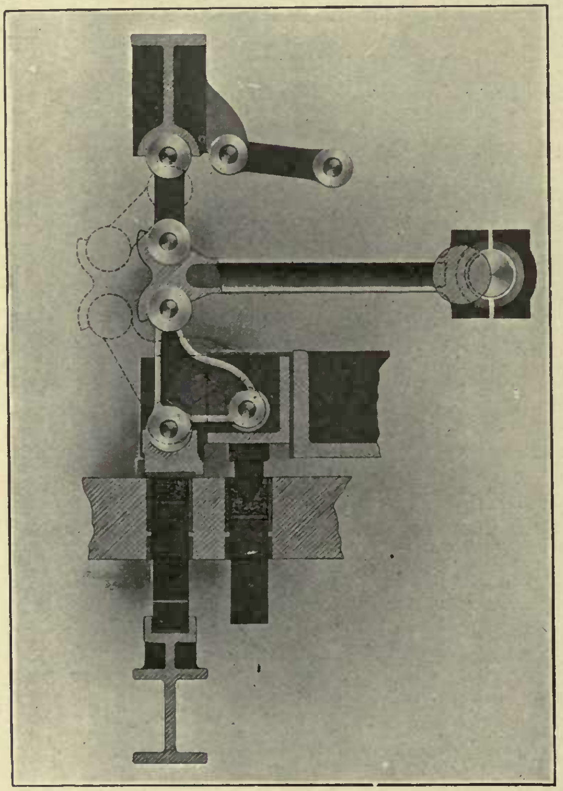


Fig. 64. Pressing Levers on "Emperor" Press
Courtesy of Sutcliffe, Speakman & Co. Ltd.

Sutcliffe, Speakman & Co. Ltd. have successfully overcome this fatal objection by fitting their "Emperor" machine with a patent expression attachment (Fig. 64). This operates by giving each brick two pressings; the first squeezes and presses the material from the centre into the corners and arrises, whilst the final pressure finishes the brick. By these means each brick is of even density throughout, with fine sharp corners and arrises. Fig. 64 shows the brick receiving the first or preliminary pressure from the right-hand plunger. The brick is then removed to the left-hand plunger, receiving the final pressure.

The bricks delivered on to the table, for removal by the attendant, should not be pushed from the moulds as in presses of the vertical type, as experience has shown that any press which pushes bricks from the moulds is unsuitable for making lime-sand or concrete bricks.

With some types of press, the box is filled improperly, the material falling in the centre and becoming more closely packed there than nearer to the sides, whilst the pressure of the machine is not sufficient to make the distribution of the material perfectly uniform. Various methods have been defined to overcome this defect. They usually consist in giving a double pressure to the material—a preliminary one to form it roughly to shape, and a final one in a fresh die as shown in Fig. 64—

but each manufacturer of presses has his own devices, and these are best explained with the machine actually present, rather than on paper.

Two methods may, however, be mentioned here. The first is the one used in the "Stanley" press of the Nuneaton Engineering Company, and consists of a measuring box with a bottom made in two parts. The box is filled with the lime-sand mixture and is brought immediately above the die. The bottom of the box is then opened suddenly so that the material falls into the die in a perfectly uniform manner.

The second method is one used in the Bernhardi presses, and consists in the use of a specially designed bottom plunger. This plunger is in two parts, working one inside the other in such a manner that during the filling of the die the outer ring of the plunger sinks lower than the inner cylinder portion and so leaves a portion of the die occupied by the plunger instead of by the lime-sand mixture. During the pressing the ring of the plunger rises until it is level with the cylinder inside it—thereby equalizing the density of the material near the edges of the die—and then both parts of the plunger travel upward at the same speed so as to complete the pressure required. As the ring portion of the plunger can be lowered as much as may be desired, the relative density of the various portions of the material may be adjusted with considerable accuracy. The fear that the double plunger would wear out rapidly is not experienced in practice.

CHAPTER XIII

THE COST OF MANUFACTURE

THE cost of manufacturing bricks made of non-plastic materials depends on so many variable circumstances that no very close figures can long remain reliable. Moreover, the prices of coal and lime vary so greatly in different localities as to make any figures which are quite accurate for one locality somewhat misleading in another. The following particulars must, therefore, be regarded as suggestive rather than of definite application to any prospective or existing works. It is, in fact, in the adaptation and adjustment of such general figures so as to meet a particular case that the services of an impartial and independent expert are so valuable. By virtue of his position he is able entirely without bias to state information which is, otherwise, unobtainable or which can only be gained in an incomplete and imperfect manner on account of the exigencies of commercial conditions.

The cost of making bricks of sand, clinker, slag, or similar materials is distributed among four factors :

(*a*) The raw materials.
(*b*) The actual production.
(*c*) Overhead expense.
(*d*) Selling expenses.

The Cost of the Raw Materials must be ascertained for the locality where the bricks are to be made. The sand, clinker, or slag will usually be obtained for a few pence per ton, but if coal and labour are cheap and bricks fetch a good price it is often remunerative to pay as much for the sand at the rate of 10*s*. per 1000 bricks.

The lime or cement must usually be purchased. It is essential that they should be of really good quality, and it is foolish to use inferior lime or cement, as the quality of the bricks depends largely on these materials. With inferior aggregate a passable brick can be made if the binding material is good, but even the best qualities of sand, clinker, or slag will only give poor results with an inferior lime or cement.

Sometimes it pays to quarry local limestone or chalk and burn it in kilns on the spot, thus producing the lime instead of buying it. There are several serious drawbacks to this arrangement, however, and the burning of the lime should not be undertaken except under skilled advice. More than one firm of brick manufacturers has been ruined by using a local limestone burned under their own supervision rather than purchasing the best quality of lime in an open market. The profit on lime-burning is not large and in most districts in Great Britain it is as cheap to purchase the lime as to burn the stone; in other countries circumstances differ greatly, and a lime-burning plant may then be desirable.

The Cost of Production includes all wages for labour, carriage, and cartage, coal, water, repairs, supplies (oil, etc.), and wastage, but *not* management, and selling expenses, depreciation, bad debts or interest on capital.

The cost of manufacturing bricks made of non-plastic materials is chiefly regulated by the cost of the raw materials, as the labour involved is exceedingly small, the plants being arranged to work almost automatically.

The cost of production may be calculated from the following data :

TABLE SHOWING THE APPROXIMATE COST OF PRODUCTION AND PROFITS OBTAINED BY FOURTEEN LIME-SAND BRICKWORKS

In Operation since	Net Profit realized per Cent.	Yearly Production in Millions	Cost of Production (Shillings)	Selling Price per 1000 (Shillings)
1903 . .	15	2	17/-	22/6
1902 . .	10–12	2	17/-	23/-
1904 . .	10	2	16/6	23/-
1900 . .	8–9	1½	16/- to 16/6	19/- to 20/-
1904 . .	8	2	17/-	21/-
1903 . .	15	3	15/- to 16/-	22/- to 24/-
1899 . .	12	2½	15/6	22/6
1903 . .	12½	3	14/6 to 15/-	21/6
1902 . .	8	2	15/-	19/-
1901 . .	4	2	15/-	18/-
1899 . .	10	3	13/6	19/6
1900 . .	9	1½	14/-	22/-
1904 . .	10	2	13/-	18/-
1900 . .	4½	2	13/-	15/- to 16/-

As regards cost of production generally, the following may be taken as representative for a plant working only in the daytime.

The cost is based on :

Safe output as 18,000 per day.

Labour at 28*s*. per week.

Sand, 2*s*. per 1000 at works.

Coal at 16*s*. per ton.

Lime at 19*s*. 2*d*. per ton at works.

Weight of 1000 bricks equalling 3.25 tons.

Working day of 9½ hours.

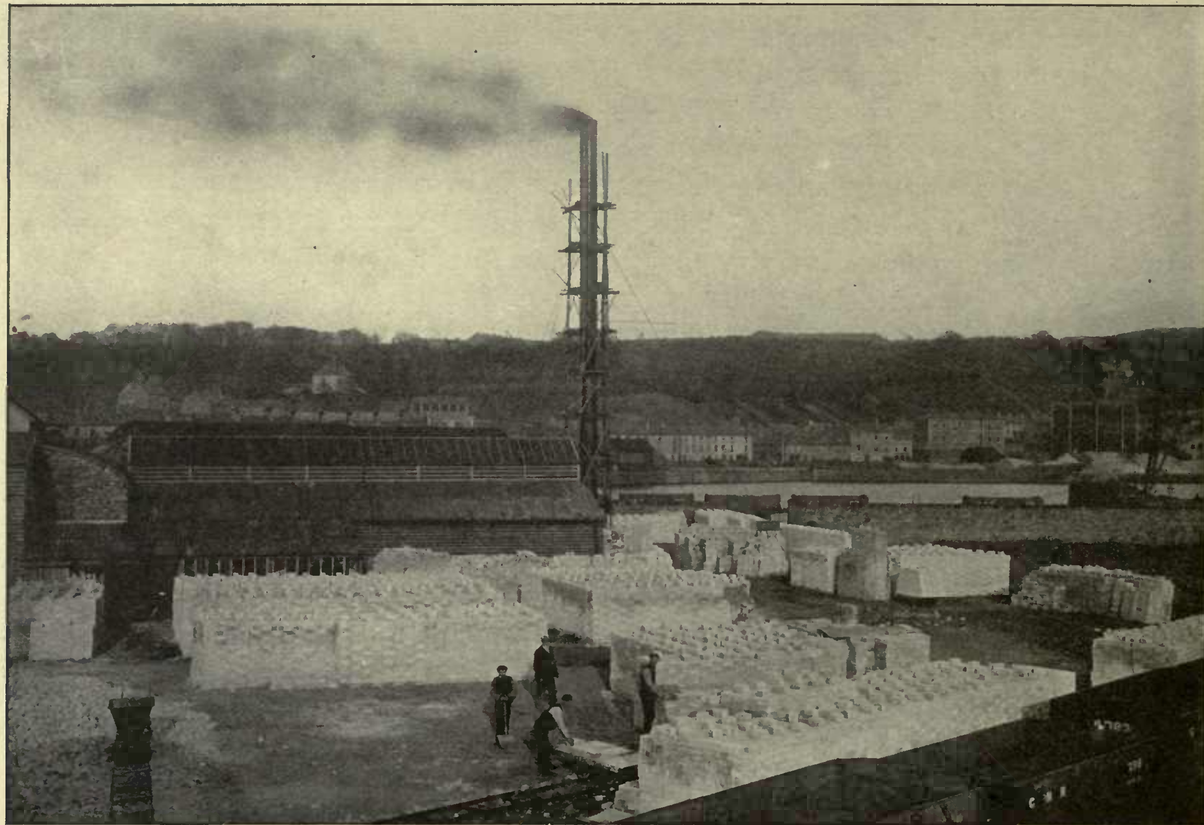


FIG. 65. A Typical Lime-Sand Brick Works
Courtesy of H. Alexander & Co. Ltd.

	£	s.	d.
Sand for 18,000 bricks and waste	1	18	0
Lime, 7 per cent., say, 4 tons	3	16	8
Coal $2\frac{1}{2}$ tons	2	0	0
Wear and tear at 1*s.* 3*d.* per thousand	1	2	6
1 man feeding sand	0	5	0
1 man grinding lime	0	5	0
1 man mixing (good man)	0	5	6
3 men at press	0	15	0
4 men wheeling and stacking	1	0	0
2 boiler men—1 day and 1 night—(good men)	0	11	0
1 engineer or mechanic	0	7	0
1 labourer	0	3	6
	£12	9	2

Cost per 1000, say, 13*s.* 10*d.*,

to which must be added management, depreciation, and selling expenses.

These figures will naturally vary according to the conditions ruling where it is intended to erect the plant.

There are obvious advantages to be gained by *working both day and night*, and by running two shifts, each of ten hours, and pressing one brick at a time, or 15,000 bricks per shift; there is less strain on the press than when using a duplex machine, the men can be more careful in handling the bricks and there is less wastage. Although the output per hour is less, the cost per thousand is not increased, as the boiler and engine are worked more economically when run continuously.

Blocks made of lime-sand will cost somewhat less than an equal volume of bricks, and will average about 12*s*. per cubic yard.

Floor plates, *slabs* and *tiles* up to 2½ in. thick cost about 1*s*. 3*d*. per square yard.

CEMENT-SAND BRICKS cost about 18*s*. per thousand, on the following data :

Sand at 2*s*. per ton or cubic yard.
Cement at 30*s*. per ton, and
Labour at 6*d*. per hour.

1000 Building bricks, 9 in. × 4⅜ in. × $2\frac{11}{16}$ in.

	£	*s*.	*d*.
2 cb. yd. sand, or gravel and sand, or breeze and sand .	0	4	0
6½ cwt. cement	0	10	0
10 hours labour	0	5	0
1000 building bricks	0	19	0

The cost of production naturally varies according to cost of labour and local prices of raw material.

Speaking broadly, the following remarks apply to all classes of non-plastic bricks :

Repairs and renewals will not average more than 1*s*. to 1*s*. 3*d*. per thousand bricks if a good plant is installed and is worked by competent men. Cheaply built plant or careless treatment may easily raise the charge for repairs and renewals to six times this amount.

Coal for the boiler (including hardening chamber) in a power-driven plant will average 3 cwts. per thousand bricks, which at 16*s*. per ton works out at 2*s*. 6*d*. per thousand bricks.

Sundry supplies may be averaged at 3*d*. per thousand bricks.

Wastage and defective bricks which must be sold under cost must be charged in full in the proper account. No kiln is used for bricks made of non-plastic materials, so that the kiln wastage and loss which are so serious in the case of clay bricks are avoided.

Overhead expenses include :

(*a*) Office salaries and office expenses (other than selling), rental rates, taxes, light, heating, stationery, postage, printing, telegrams, telephone.

(*b*) Interest on capital, depreciation, sinking fund, depletion of supply of material, bad debts.

(*c*) Insurance against fire, employer's liability, sickness and bad debts.

Many brickmakers have failed because they omitted to take into account some of the items included above as overhead expenses, particularly those in Section (*b*). It is of the greatest importance that the depreciation of the machinery should be so calculated as to provide in ten years a sum equal to the whole cost of the plant. These amounts should be invested outside the brick business.

It is not necessary that the amount charged to the depreciation account should be the same for each year. It is generally wiser to charge a smaller proportion for the first three years and an increased amount for the remainder of the period. Thus, if the machinery and plant (apart from buildings) cost £4000 it would hamper the business unduly to charge £400 for each of ten years as a depreciation account, and a fairer method would be to charge £100 for the first year, £200 for each of the second and third years and £500 for each of the remaining years.

Such an arrangement gives a business time to become established ; should it fail at any time before the sum charged to depreciation account plus that realized by the sale of the plant equals the original cost, the loss must be regarded as one of speculation.

The depletion of supply of material is a factor often overlooked in calculating the cost of manufacturing bricks. It is best managed by the payment of a royalty based on the amount of material used.

The charge for interest on capital is one which is frequently a source of contention among people who are the sole owners of a business, many of them arguing that as they take the whole of the profits there is no need to make any charge for interest. It must be remembered, however, that if the owner had his money invested elsewhere it would, presumably, be earning interest, and that unless a charge of 4 or 5 per cent. is made for interest on capital, it is quite possible that a business may be a source of loss without this fact being realized. For a similar reason the owner (if he manages his works himself) should charge the firm a " reasonable salary " for his services.

It is always better to " know the worst " about a business if things go wrong with it, whilst if it prospers, such rigorous accounting as that suggested gives the owners a feeling of added security.

Selling expenses include advertising, salaries and expense of travellers, commissions, samples, and all expenses due to the cost of selling.

It is unwise to include these in the general overhead expenses, though this course is frequently adopted. By keeping them quite separate a better control of the selling expenses is facilitated.

Net Profits

Broadly speaking, the costs of manufacturing bricks from sand, clinker, or slag is always less than that of making clay bricks; the ratio usually proves to be about 3 : 4 in equally well-managed works. Unfortunately, many existing brick yards are run on a basis which is entirely unbusinesslike and can only be regarded as selling at a price which is regardless of the true costs of manufacture. So far as the author is aware—and he has exceptional facilities for obtaining accurate information on the subject—it is impossible in the United Kingdom to make a profit on clay bricks which are sold at less than 19*s*. per thousand, except in one part of England where the manufacture is on an exceptionally large scale under conditions and with material of an unusually favourable nature. Some manufacturers of clay bricks believe that they can make bricks at less than this sum without suffering any loss, but a closer examination will show that some essential expense has been omitted or that some material or expense is charged to some other firm, and not, as it should be, to the brick works. Thus, a colliery will often deliver the clay free of charge to a brick works belonging to the firm, an engineering works will do all repairs free of charge, or other arrangements may be made which are convenient on account of their simplicity, but they effectively prevent the true cost of the manufacture of the bricks being known. Hence, in comparing the estimated cost of producing bricks from non-plastic materials with the statements emanating from other works care must be taken to ensure that such statements are *complete* estimates, and do not merely give a portion of the cost.

Normal Profits. Under average conditions a lime-sand plant selling bricks at 25*s*. per thousand gives a clear profit of 15 per cent. on the capital invested, after providing interest and depreciation calculated in the manner suggested in this chapter.

Exceptionally high profits are obtainable in some lime-sand brick plants. For instance, where a large quantity of sand overlies a valuable clay or other mineral, and where, in the ordinary way, the cost of removing this sand would be added to the cost of obtaining the clay or mineral. By making the sand into bricks, what would otherwise be a loss is converted into a source of profit, or it may be regarded as reducing the cost of obtaining the underlying mineral.

Occasions not infrequently arise where sand has to be removed in order to clear or level an estate for building purposes. Under ordinary circumstances the excavation and removal of this sand would add very considerably to the cost of preparing the site for building, but if the sand is converted into bricks on the spot a very great saving is effected, and a good profit can usually be made on the sale of the bricks.

CHAPTER XIV

USES OF BRICKS MADE OF SAND, SLAG, OR CLINKER

BRICKS made of non-plastic materials such as crushed rocks, sand, slag, or clinker are suitable for almost all the ordinary purposes for which bricks made of clay are employed.

For certain purposes there can be no doubt that a properly-made clay brick is infinitely superior to any made of lime and sand, but for the more ordinary purposes for which cheaper bricks are needed it is frequently possible to produce bricks which can be made without the costly firing in kilns, and in districts where clay is absent, and consequently clay products are costly, it is of the greatest importance that other minerals or mineral products should be used as substitutes.

Quite apart from the question of competition, there is a large field for the use of bricks made of sand or crushed rock, particularly in those districts where no good building stone is to be found, but where a poor or good sand is to be found in abundance. In many ways the bricks made of the materials just mentioned go through less processes of manufacture, and consequently the number of wasters is proportionately less than with bricks made by other methods, and for many purposes the greater strength and durability of the best clay bricks is unnecessary, and lime-sand bricks will then prove satisfactory, and in many cases bricks made from clinker or slag will be equally satisfactory.

The great accuracy of shape and uniformity of size of such bricks are strong arguments in their favour, and in many localities they may be used to replace building bricks with the utmost satisfaction.

The appearance of bricks made of clinker or slag—and occasionally that of lime-sand bricks—is considered by some architects and other people to be unsuitable for facing bricks, but this is largely a matter of artistic taste. New buildings look equally well, no matter whether lime-sand bricks or clay bricks are used, and whilst the clay bricks have an undoubtedly more artistic appearance when old and in the country, the dust and dirt of industrial centres soon spoils this effect by coating the buildings with a film of grey sooty matter. Hence, for structures built for commercial utility rather than for æsthetic appearance, bricks made of non-plastic materials have proved fully as satisfactory as those made of clay, and have, indeed, several advantages over the latter (p. 122, *et seq.*).

Æsthetically, it is difficult to understand why architects who are enthusiastic in the use of small blocks of stone should object, as some do, to lime-sand bricks,

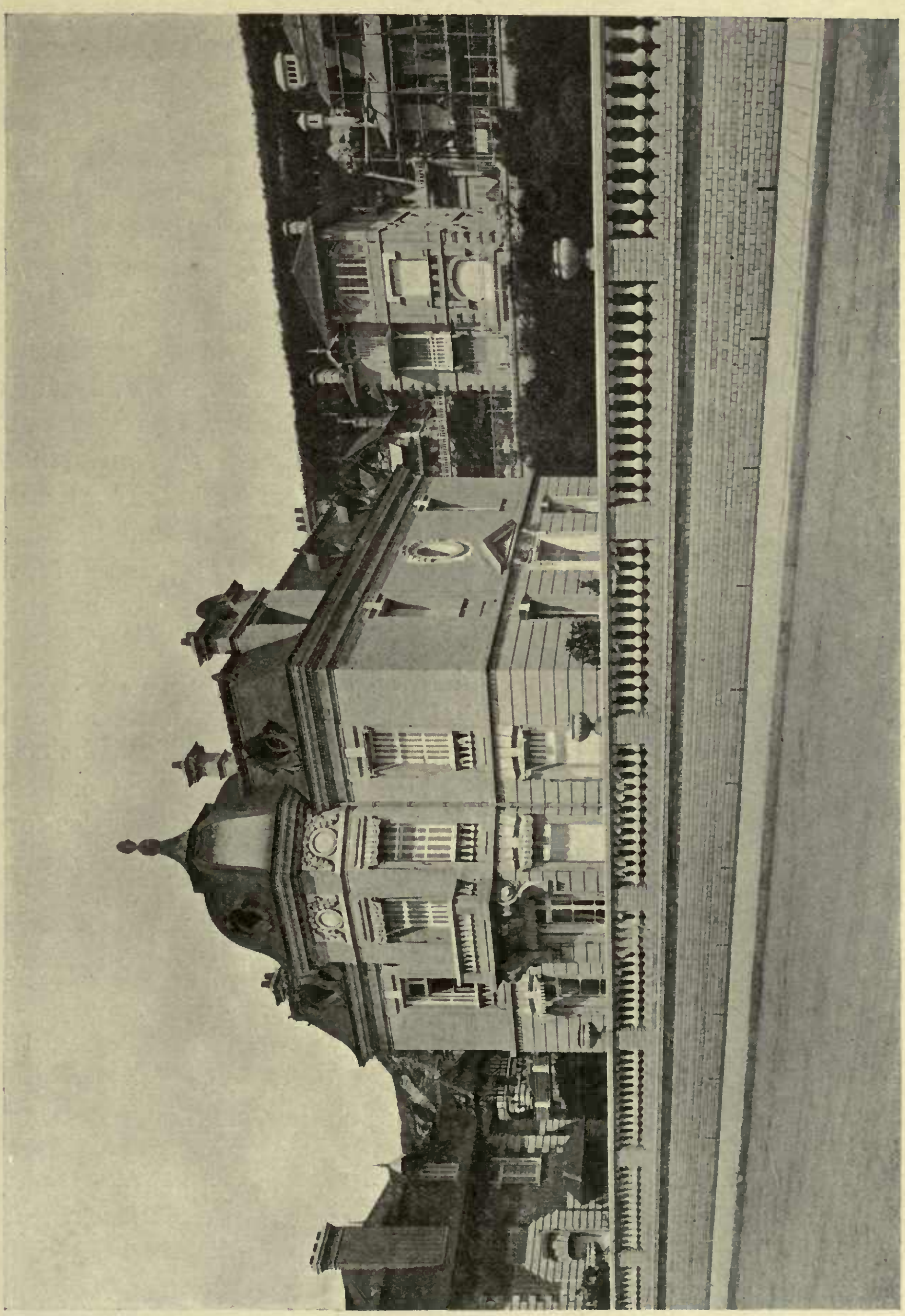


FIG. 66. Villa and Boundary Wall built of Lime-Sand Bricks
Courtesy of Sutcliffe, Speakman & Co. Ltd.

which are precisely the same material but are produced artificially instead of naturally. The slight evidence on which some architects have, in the past, rejected lime-sand bricks is shown in the fact that some of these same architects when given to understand that a portion of a lime-sand brick was part of a block cut from natural sandstone have admired it and have agreed to name it in some of their specifications !

An equally unsatisfactory recommendation is that of the Committee appointed by the Dutch Minister of Commerce in 1908, which states that bricks other than those of lime-sand are preferable for buildings of exceptional durability for the reason that lime-sand bricks have not been known long enough to have their durability proved ! Such a reason may have been right ten or fifteen years ago, but it is simply fatuous at the present time.

There are several other inconsistencies in the report of this Committee which greatly detract from its value. Thus, the statement is made that lime-sand bricks should not be used where decomposing vegetable matter has access to them, but the committee adds that the durability of piles made of lime-sand shows that lime-sand bricks can be used in such situations. This inconsistency arises from a misunderstanding of the action of acids on the bricks, it being thought that because acids (like water) will dissolve out any surplus lime present, they must, therefore, destroy the bricks. In reality they do nothing of the kind, lime-sand bricks being as resistant to acids as is concrete.

The architectural value of lime-sand bricks from the æsthetic point of view may be clearly seen in Fig. 66, and in the Frontispiece. In this connection it should be observed that it is important architecturally that the mortar should be composed of the same material (lime and sand) as the bricks, or should offer a strong contrast. The ease with which lime-sand bricks can be carved, offers great facilities for architectural forms and decorations not generally attainable in brickwork and so adds to the value of this kind of bricks. Almost any shape of moulded bricks can be made of lime-sand and large blocks weighing upwards of three tons can also be manufactured without difficulty. These large blocks can be sawn, cut, and chiselled by machinery or by hand in precisely the same way as natural sandstone.

Leaving the question of facing bricks aside for the moment, as one in which the temperament of the architect must be the chief deciding factor, it may be said that for all building purposes bricks made of sand, clinker, slag, or similar materials are fully as suitable as bricks made of clay.

For the interior of factories, lime-sand bricks reflect more light than bricks made of red-burning clay, and they present so uniform a surface that less plaster is required when the walls have to be finished with this material.

For the reason just mentioned, bricks made of non-plastic materials are also excellent as a basis for rough cast, stucco, and similar work and prove very economical in this respect.

Where *loads* are to be carried (as in the pillars supporting girders) lime-sand bricks are often preferred to bricks made of clay, because there is some slight uncertainty about the strength of the latter, whereas the strength of lime-sand bricks may be relied upon and could be guaranteed if necessary. The number of water-towers, silos, bridges, and similar structures which have been built of lime-sand bricks with complete satisfaction to all concerned forms a standing testimony to their strength and durability under actual load conditions.

For *foundations* lime-sand bricks have proved highly resistant to damp, frost, and weather (pp. 118 and 119).

For *roads*, bricks made of slag or clinker are particularly good.

Those who have travelled in Germany, especially in the iron-making districts, must have been struck, if they are at all observant, with the wonderfully fine roads which are in vogue there, roads which seem to stand any amount of the heaviest traffic without breaking down. The secret is that the Germans go to the trouble of working up the slag or refuse from the iron furnaces into bricks. The bricks are then laid like stone pitches, usually on a cement bed with cement joints. The surface of such roads is not only hard, but tough, and the amount of wear-and-tear which they will stand is something extraordinary. It is a pity that there is not a little more enterprise shown in regard to this matter in our own country.

The utilization of some of the enormous heaps which disfigure part of the country would prove doubly profitable, for not only would the cost of tipping such material be saved, but the bricks so made could be sold at a profit.

Brick roads, if properly laid, offer a much better surface than other materials, so far as the effect of traffic is concerned; they are much cleaner than any other road material and avoid the dangers and disadvantages of macadam on the one hand, and excessively hard stones, like granite, on the other. The value of bricks for road making is only just beginning to be appreciated, but wherever they have been skilfully laid, they have proved an unqualified success.

For *water works* and *drainage* purposes, and for *lining wells*, lime-sand bricks have been extensively used in various parts of the world and are quite satisfactory. For *underground work* their value may be gauged by noting that in the neighbourhood of Gorlitz a well, constructed in 1904 and over 100 ft. deep and 6 ft. diameter, is lined exclusively with lime-sand bricks which in 1913 are as good as when first used. The fact that over two million lime-sand bricks were used in the Berlin Underground Railway, and have proved quite satisfactory, is a further evidence of the value for underground work. For *colliery shafts* the fact that the strength of the bricks can be guaranteed, combined with the great uniformity of shape is of great importance, especially as collieries are not infrequently built in districts where sand is cheap and the clay is unsuitable for the production of the best colliery bricks.

For *chimney stacks*, lime-sand bricks have proved highly satisfactory and have been equally valuable for lining domestic chimneys and fireplaces. In the latter they can replace firebricks at a considerable reduction in cost. On account of their resistance to heat they have also been used successfully for boiler setting.

The use of lime-sand bricks for refractory purposes requires some care, as they are not really firebricks (p. 116) though they may replace the latter in a large number of cases. Bricks made of sand, slag, or clinker are particularly suitable for the construction of chimneys on account of the heat-resisting qualities. They often prove cheaper than bricks made of clay as the necessity for a firebrick lining is avoided when sand, slag, or clinker bricks are employed.

Firebricks. If lime-sand bricks are made of suitable materials and are afterwards burned in a kiln (p. 117) they may be used in the construction of all except the hottest parts of furnaces for melting steel and for all parts of furnaces used for many other metallurgical purposes. They have, in fact, been used in enormous quantities for several years past under the name of "selected silica bricks." The fear that they would spall and peel in use is not experienced in practice if the bricks are properly made.

Several kilns of the Hoffman type have been built of lime-sand bricks especially for use in lime-burning and after being in regular use for several years—in one case since 1901—they have proved to be fully as serviceable as kilns built of burned clay bricks.

Glazed Bricks. Lime-sand bricks may be enamelled, if required, though less easily than are bricks made of the best fireclay, as the surface of the latter is composed of much finer grains. The composition of the enamel used for lime-sand bricks is, naturally, maintained as a trade secret. The difficulties which have been encountered in its production and application are such as to warrant the payment of considerable sums of money for detailed information respecting it and, for this reason, such information cannot be made public in the present volume. It is sufficient to state that lime-sand bricks can be enamelled satisfactorily at a cost notably less than that of making enamelled bricks of fireclay.

Specifications. In order that there will be no difficulty in securing bricks which shall be suitable for the purpose various specifications have been adopted by a number of public and semi-public bodies. The most important of the provisions of these specifications for bricks used for building purposes are shown in the following Table, but it should be observed that, with the exception of a minimum crushing strength of 2000 lb. per square inch in Germany, none of the specifications are compulsory, except by agreement.

A is a specification used by a number of important architects in Germany.

B is from the report of the Committee appointed by the Dutch Minister of Commerce in 1908.

C is the specification of the Bureau of Buildings, Manhattan, New York, U.S.A.

In the United Kingdom no regulations are in force for building bricks, but specifications drawn up by engineers and architects are usually confined to limiting the porosity and minimum crushing strength.

It is an obvious fact that the limits given in the following Table will have to be made much narrower if they are to be any use; at present their scope is so wide that it will permit the use of weak stones or bricks as well as strong ones. Moreover, what is needed is a test that can be applied without destroying the bricks. The crushing strength merely shows that certain bricks are of the desired strength ; as these are destroyed in the test they cannot be used again, and it is by no means a fair argument to suppose that because selected bricks in a stack are good that all are good. Hence, the desirability of a test which can be applied to bricks without in any way damaging them. Apparent density and water absorbtion or porosity

	A	B	C
Crushing strength in lbs. per sq. in. :			
First quality—			
Average	—	2840	—
Minimum	—	2556	—
Second quality—			
Average.	2000	2130	3000
Minimum	—	1917	2500
Texture of fracture when broken .	—	Uniform	—
Porosity average (per cent. by weight	13–21	15	15
Maximum	21	—	20
Minimum soluble silica, per cent. .	5	—	—
Modulus of rupture—			
Average	—	—	450
Minimum	—	—	350
Maximum loss in compressive strength when saturated with water . .	—	—	33½ per Cent.

tests appear to be of this character, and if the limits were made narrow enough it is probable that they would be sufficient for all ordinary purposes, though the makers might still continue to make crushing tests for their own guidance, and to have tests of the proportion of soluble silica made in order to control the efficiency of their treatment. With regard to this soluble silica, as the sand grains do not naturally adhere to each other, it is only the amount of silicate uniting these grains together which gives the bricks their strength. Not the total amount, however, but the amount distributed to the best advantage in the form of a thin coating of silicate around each grain of sand is that which is of use ; isolated masses of silicate being of no value at all. This can be observed with a petrological microscope far better than can be ascertained by any kind of chemical test, and it appears desirable that some form of microscopical examination should be made an essential feature of all tests of lime-sand bricks.

Some localities are particularly adapted to the manufacture of lime-sand bricks but if the prejudice in favour of clay bricks is to be overcome, the makers of lime-sand bricks will have to convince builders and others by means of comparative figures. They must also be prepared with some sort of guarantee, and then they will find that, in the right districts, there is ample opportunity for making a good profit from bricks made of non-plastic materials.

APPENDIX

TESTING THE LIME

THE apparatus required for testing the lime used (*see* p. 20) is as follows :

1 iron mortar pestle.
1 sieve with 75 holes per linear inch.
1 chemical balance.
1 set weights.
1 Burette to hold 100 c.c.
1 glass stirring rod.
6 beakers, 12 oz. capacity.
1 quart *normal* hydrochloric acid solution.
4 oz. of phenolphthalein solution in bottle.
1 lb. sal ammoniac.
1 teaspoon.
1 bunsen-burner or spirit-lamp.
1 tripod stand with wire gauze.
2 watch glasses for weighing lime.

This apparatus can be obtained for about £6. Each subsequent test after the first will cost about 6*d.* in chemicals, if the acid is purchased, or 3*d.* if the acid is prepared by the works chemist.

TESTING THE LIME-SAND PASTE

The apparatus above mentioned may be used for testing the paste just before it is made into bricks, or the bricks before they are sent to the hardening chamber. For this purpose 2.800 grammes of the material is weighed accurately and is placed in a beaker with twice its volume of water, and is well stirred with a glass rod so as to make a thin cream. If preferred, a glass-stoppered bottle may be used instead of the beaker and the water and sample shaken vigorously.

Twenty drops of phenolphthalein solution are then added and then the standard acid in small quantities, until the red colour remains permanently discharged even after shaking or stirring. If normal hydrochloric acid is used, each 1 c.c. of the acid corresponds to 1 per cent. of lime in the sample.

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