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AND

CLAY PRODUCTS

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PITMAN'S COMMON COMMODITIES OF COMMERCE

CLAYS
AND
CLAY PRODUCTS

BY

ALFRED B. SEARLE

CONSULTING EXPERT IN CLAYS, CLAY PRODUCTS, AND ALLIED MATERIALS; LECTURER ON BRICK-MAKING UNDER THE CANTOR BEQUEST, ETC.

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"BRITISH CLAYS, SHALES, AND SANDS"; "THE CLAYWORKER'S HANDBOOK"; "MODERN BRICKMAKING"; "BRICKS AND ARTIFICIAL STONES"; "CEMENT, CONCRETE, AND BRICKS"; ETC., ETC.

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PREFACE

This volume, like the others in this series, does not aim at exhausting the subject with which it deals. On the contrary, its chief aim is to give the commercial man sufficient insight into the nature of the various materials and products described for him to realise, in broad outline, the processes involved in their treatment and the extent to which they may be used for the purposes of his own business.

Few people, except those who are actually engaged in the manufacture of clay products, have any idea of the wide ramifications of the industries connected therewith, yet, if clay products were suddenly removed and became irreplaceable, the loss among both primitive and civilised peoples would be incredibly great. Vast and important as is the Iron and Steel industry, it is in many ways only secondary to the trades connected with clays and clay-products; indeed, without the latter, the very production of iron would become practically impossible, architecture would, in many districts, be stifled, and the most evident signs of civilisation would be absent.

To know something of the industries connected with so important a subject should form part of the education of every commercial and business man, and it is for such that this volume has primarily been written. No pains have been spared to express what is written in as simple terms as the complex nature of the subject permits, whilst at the same time every effort has been made to give the most recent information on such important points as the constitution of clays and certain clay products. In this respect much progress has been made during the past few years, with the result that the nature of clays is much better understood than it was formerly, though even at the present time it is extremely difficult to find a definition of the term *clay* which is entirely satisfactory to all users. The requirements of the engineer are often quite different from those of the builder, and the potter desires properties which are entirely opposed to those required by the manufacturer of firebricks, whilst the maker of ultramarine, cement and other products of a chemical nature, can make use of clays which are of no value in other branches of industry. Yet the materials used by all these people are, notwithstanding their wide diversity, known as *clays*. The reader who once realises this fact will not find it difficult to understand that the study of clays and their products has a fascination peculiarly its own as well as a commercial importance of the highest value.

There is a fairly large literature of clayworking and allied industries, but much of it is inaccessible to the ordinary business man ; readers who wish for further information should consult the volumes mentioned on page 158.

The Author is grateful to those who have provided the illustrations (their names are attached to these) ; also to Mr. E. R. Bradforth—a member of his staff—for assistance in seeing this volume through the press and for preparing the Index.

ALFRED B. SEARLE.

SHEFFIELD,
August, 1915.

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CHAPTER I

THE ORIGIN AND FORMATION OF CLAYS

THE origin of clays is largely obscured by the many changes which they have undergone since they were first formed. Moreover, the greater part of the clays now known must have been formed at periods so long before the advent of mankind, that it is impossible to do more than speculate as to the sources from which they have been derived. In these speculations, the aid of geology, chemistry, mineralogy and many other sciences, is used with great advantage, but when all is said the real origin of clays still remains a matter of deduction from the observed facts rather than one of actual or experimental knowledge.

So far as can be ascertained, all clays are products of the decomposition of certain rocks, of which *felspar* is the most typical, though the variety of such rocks is extremely large. All these rocks are composed of silica, alumina, and some base such as lime, soda or potash ; the silica and alumina being combined so as to form an acid (a so-called alumino-silicic acid), which is in turn combined with the base to form the felspar or other rock. Extensive investigations have shown that it is only from alumino-silicate rocks that clays can be produced.

The decomposition of the felspars and other clay-forming rocks appears to have been gradually effected by the action of the weather, including that of water, whereby the base (lime, soda or potash) is removed and is taken away in solution, whilst the residue consists of a mixture of alumino-silicic acid (clay) and free silica (quartz), together with whatever portions of the original rock have escaped decomposition. Usually, the clay particles are so fine that they are carried along by the water for some distance, but they gradually settle and form a clay deposit. As various geological changes occurred, the original clay deposits were distorted or destroyed and the clay was carried still further away from its place of origin and was again subjected to the action of water and to any impurities which the water happened to contain. The result of the prolonged action of water appears to have effected very important changes in the nature of the clay, as well as causing it to become contaminated with various materials, so that when the clay was again carried in suspension by the water and was again allowed to subside and form a deposit; the latter consisted of material having quite different properties from those of the original clay. The difference is not alone due to the impurities present, but is largely due to some constitutional change in the clay itself—a change whose nature has not yet been fully elucidated, but the most marked characteristic of which is the great increase in the plasticity of the clay. In subsequent geological periods many clays have been carried away from their places of deposition an indefinite number of times, during which they may become either purer or more contaminated with impurities according to the conditions to which they were subjected. Thus, in some parts of Derbyshire there are clays which appear to have formed but a small proportion of the constituents of an impure limestone ; the limestone has subsequently been removed by solution in water impregnated with carbonic acid, whilst the clay, being insoluble, has been left behind in pockets in the hills.

What appears to have occurred in the formation of the huge beds of clays in the British Isles may be very briefly described as follows—

The igneous rocks were first formed, and these were largely composed of the minerals which, when decomposed in certain ways, result in the formation of clays. The action of the weather and other natural agencies on these primary rocks was to wear them down and to carry them to the sea where they formed the first of the sedimentary or deposited rocks. During this process the clays would be formed. Whilst immersed in this manner, various changes in composition and physical properties occurred so that a further series of minerals was produced. The earliest available materials of this nature are the Torridian and Cambrian rocks—chiefly sandstones and slates. The land then appears to have risen above sea-level, but to have subsided again during the period in which the Silurian sandstones and shales were deposited on the Cambrian beds, or rather on what was left of the latter. The Silurian period must have been an unimaginably lengthy one, as there are still deposits belonging to it which are 20,000 feet in thickness. It was accompanied or followed by a period of active volcanic action and of earthquakes which caused the deposits to be folded into curious shapes and placed some of them at a steep slope instead of leaving them in their originally flat position. The further action of the weather again removed a large proportion of the surface of the earth, and thick masses of sandstone and clays accumulated and formed what are known as the Old Red Sandstone deposits. A further period of volcanic action then occurred, and the whole of the British Isles was again raised above sea-level, only to be again worn down by the action of the weather with the formation of the clays and rocks known as the Coal Measures. Further local risings then followed, and in the enclosed hollows inundated by the sea, the Permian clays and rocks were laid down. After a further indefinite period, the water-level was again lowered, and desert conditions appear to have prevailed, only to be followed by a further denudation which resulted in the formation of the New Red Sandstone and the Triassic clays. After this there appear to have been many changes in the relative heights of land and sea, particularly in the south where the Lias, Ooolite and Wealden clays and rocks were deposited. These were followed by the formation in the sea of vast quantities of shells, which eventually settled to the bottom and formed the Chalk beds. After this a gradual rising of the ground again occurred, and the Tertiary clays and rocks were formed by the denudation of the earth's surface. During the Pliocene period which followed, the eastern counties were again submerged and the Pliocene clays were laid down. After this the temperature fell greatly, intense Arctic conditions prevailed, and the huge glaciers or rivers of ice denuded the hills and valleys, carrying boulders along and grinding some of them to powder in their journey until, as the ice melted and the materials carried by it were deposited they formed a huge blanket of *drift*, a part of which forms the well-known Boulder clay of the North and Midlands. Since this Glacial Period the changes which have occurred are those which can be seen at work at the present time, the more violent risings and subsidences of former ages being less noticeable since mankind has inhabited the earth, though these changes are still going on, slowly and relentlessly as ever, as may be seen from an examination of the East Coast and other exposed pieces of land. In fact, every streamlet is contributing its share to the present denudation and to the formation of a fresh deposit of material in the beds of the oceans now in existence.

The result of all these changes in the relative positions of land and water during an innumerable number of years has been the formation of an extensive series of layers or beds of various kinds of rocks, including clays, in approximately the order shown in the Table on the next page, the most recently deposited being uppermost.

The reader's present interest being in clays, these are given the chief prominence in the Table, though actually they form a comparatively small proportion of the deposits of some periods, and many clays are so contaminated with impurities as to be almost useless. For this reason it is necessary to examine any clay deposit carefully, before its value can be ascertained, as geologists include under the term *clay* all materials which become plastic when mixed with a little water or are so closely associated with clays as to render their separation inconvenient for the purposes of geological classification. Unless this is borne in mind great disappointment may result from reading a geological statement that certain clays are abundant in a given locality: such a statement may be of much greater geological than commercial importance.

TABLE SHOWING THE RELATIVE GEOLOGICAL POSITIONS OF VARIOUS CLAYS.

Geological Systems.	*Groups.*	*Clay Contents.*
Post Tertiary		Cement clays, silts, fluviatile and alluvial clays, brick earths and boulder clays.
Tertiary	Pleistocene Miocene Oligocene Eocene	Brick earths, pottery clays, ball clays.
Cretaceous	Chalk Greensand Wealden	Brick clays.
Jurassic	Oolite Lias	Brick clays.
Triassic		Brick clays.
Permian		The so-called red marls (brick clays).
Carboniferous		Brick clays, fireclays, ganister.
Old Red Sandstone		Slaty shales, brick clays, and slates.
Silurian		Slates and slaty shales.
Ordovician		Slates and slaty shales.
Cambrian		Slates and slaty shales.
Pre-Cambrian		Schists and serpentines.
Metamorphic		Clay slates and schists.
Igneous		Granites, etc. These are the clay-forming rocks which, on decomposition, form the primary clays (china clays, etc.).

CHAPTER II

THE VARIETIES OF CLAYS

FROM what has been stated in the previous chapter, it is clear that there must be many varieties of clays, and that if there were only one chemical compound which is the essential ingredient of all clays, yet the changes they undergo, from the time of their formation by the decomposition of the original igneous rock to the time when the clay is quarried or mined, are so great and so numerous, that the original nature of the clay substance is hardly recognisable. The ages which have elapsed since the formation of the clays found even in the most recent deposits are so long that it is not surprising that there are almost endless variations in clays. Some people have even gone so far as to say that no two samples of clay are precisely alike, and whilst there is much truth in such a statement, it is admittedly an extravagant one.

Without going too deeply into the composition and chemical constitution of the various clays—this would be too complex for those for whom this volume is primarily intended—it will be found that there is in all clays a varying proportion of one or more very highly complex substances which are known by the names of *alumino-silicic acids.* These are the essential substances of all clays, and when any sample of clay has been freed as far as possible from all its impurities, it will consist almost entirely of alumino-silicic acids.

There have been several writers who regard clays as containing one definite chemical compound, to which they give the name *clay substance* or *true clay;* such a view is convenient, but probably incomplete. In the present writer's opinion there are numerous alumino-silicic acids whose chemical composition is the same or almost the same as that of the purest clays, but owing to the great complexity of these acids the arrangement of the various atoms in them may be quite different. Hence, it is probable that the clays form a large and important class containing certain alumino-silicic acids which may, for convenience, be regarded as almost identical and, therefore, grouped together as "clay substance," though a closer investigation will show that the clay substance from different clays is by no means identical, and is really composed of different acids all having in common a general percentage composition and certain chemical properties. Several similar cases occur in organic chemical compounds, especially among the dyes, but the greater ease with which organic compounds can be decomposed and their greater activity at temperatures at which experiments may conveniently be carried out, has enabled their structures to be studied more thoroughly than has that of the various clays. So much work has been done on clays in recent years, however, that with the research work now proceeding on the subject, there is great hope of the constitution of the purer clays being known definitely in the near future ; the investigation is, however, accompanied by so many difficulties that it may be some years before practical use can be made of the results of present researches.

From what has already been discovered, it is reasonable to conclude that the purest clays are all alumino-silicic acids, and that the clays found in Nature are impure forms of these acids.

The alumino-silicic acids (of which clay forms a portion) are white solid substances, which may occur in the form of very minute plate-like crystals, but which are usually obtained in particles of no particular shape, to which the expression *amorphous* is usually applied. On analysis, all the alumino-silicic acids appear to be composed of alumina, silica and water, but the elements composing them are not necessarily, or even probably, grouped in this manner, but in an extremely complex arrangement of aluminium, silicon, hydrogen and oxygen atoms, which on analysis rearrange themselves forming alumina, silica and water. In spite of their great complexity all the alumino-silicic acids occurring in clays have a similar composition approximately corresponding to—

Alumina	39·45 per cent.
Silica	46·64 „ „
Water	13·91 „ „

but the proportion of water and silica vary greatly, and imply the existence of acids somewhat richer in silica, especially in the fireclays and in some red-burning clays. As the proportions given above correspond to the chemical formula Al_2O_3, $2SiO_2$, $2H_2O$, this formula is sometimes stated to be that of pure clay substance. Such a statement is apt to be very misleading, as it merely represents the lowest proportions in which the various elements are present, and in all probability the formula is much more complex though the same proportions may be maintained. If this is the case it is easy to see that a rearrangement of several of the atoms in a complex grouping may produce an entirely different kind of clay, whilst the substance as a whole is still an alumino-silicic acid.

Like all acids, clays have certain well defined properties; they differ from the commoner acids of commerce in being solid, and as they do not become fluid except at exceedingly high temperatures, their acid properties have largely escaped the attention of investigators. At a bright red heat, the acid properties of clays are readily observable, such as the manner in which they corrode limestone and combine with this and other bases forming a "salt" (molten slag), just as commoner acids do at appropriately lower temperatures. Like all strong acids, clays also decompose salts of weaker acids, replacing the weaker acid and setting it free. This occurs in the manufacture of salt-glazed ware, the clay of which the goods are made decomposing the common salt (sodium chloride) thrown into the kiln for the purpose, forming a soda glaze and setting free the hydrochloric acid in the form of vapour. Like the complex organic acids, clays are decomposed by heat with evolution of water, and in a variety of other ways their strongly acid character may be demonstrated.

It is very important to remember the fact that clays are essentially acids, as many of their most important properties are due to it.

The purest alumino-silicic acids which have been prepared show no signs of fusion when heated to a temperature below 2,000° C. (3632° F.), but almost all clays fuse below this temperature on account of the impurities they contain. Alumino-silicic acids are decomposed on heating to a dull red heat (about 500° C.) and then lose water, forming an amorphous mass which if only slightly heated is readily soluble in acids, but if heated strongly becomes insoluble. The chemical composition of this heated material is not definitely known; in some respects it behaves precisely like a simple mixture of free silica and free alumina, whilst in other respects it behaves like a compound. Whatever may be its nature it is an essential material in all bricks, pottery and other clay-ware, and on its general resistance to acids and other substances the practical value of these articles depends.

The impurities found in clays are so numerous and so complex that they render it almost impossible to obtain pure alumino-silicic acids from some clays, and the slow rate at which these acids react makes it appear as though the artificial production of clays is beyond the power of mankind on account of the periods required. It is quite within the bounds of possibilities that researches now being prosecuted on the production of clays from their elements may be concluded with unexpected suddenness and that what now appears to be almost impossible may be accomplished.

Meanwhile, it is important to observe that the clays found in Nature are never pure; consequently they differ greatly in many of their properties from the alumino-silicic acids which form their chief constituents. Nevertheless, in so far as it is possible to purify clays, so far does their composition approach that of the pure acids, and there is no known fact which is in opposition to the view stated above that the essential ingredient of all clays is one or more alumino-silicic acids.

If any natural clay is examined it will be found to consist of grains of various sizes which can be separated from each other by means of a series of sieves of different mesh, the separation being more readily effected if the clay is first mixed with about twice its weight of water and sufficient additional water added to the residue on each sieve. In this way a natural clay may be separated into one or more of the following groups: small stones and gravel, sand of several degrees of fineness, and a material so fine that it will pass completely through the finest sieve procurable, that is, one having 250 holes per linear inch. This finest portion contains the whole of the true clay, the coarser portions being readily seen to consist of sand or stone.

The finest particles removed from the clay may be still further sub-divided by subjecting them to the action of a stream of water flowing at a carefully regulated speed, and it will then be found that all materials which are not carried away by a stream flowing at the rate of 2 ft. per hour, are not of the nature of clay. The extremely fine particles which are carried away by this slow-flowing stream contain all the true clay in the natural material, though even then the clay is not free from impurity. This represents the nearest approach to pure clay which can be obtained on a commercial scale, and it is significant of the wide variety of materials commonly included in the term "clay" that most natural clays do not contain more than half their weight of true clay. In sharp distinction from these impure materials are the *china clays*, which contain about 90 per cent. and may occasionally contain as much as 98 per cent. of pure alumino-silicic acid. Between these wide limits are the clays of commercial value, usually designated by the purpose for which they are generally employed, as *brick clays*, *pipe clays*, and *pottery clays*, or by some term indicative of their nature as *fireclay*, which is resistent to heat, *ball clay*, which is sold in the form of blocks or balls, etc. Space does not permit the mention of more than a few of these varieties of clays; for others the reader should consult one of the larger books mentioned in the Appendix at the end of this volume.

Alluvial clays are those formed by rivers and shallow lakes. Alluvial deposits are usually irregular in composition and rather thin, though some of the Thames alluvium is over 60 ft. thick. Alluvial clays usually

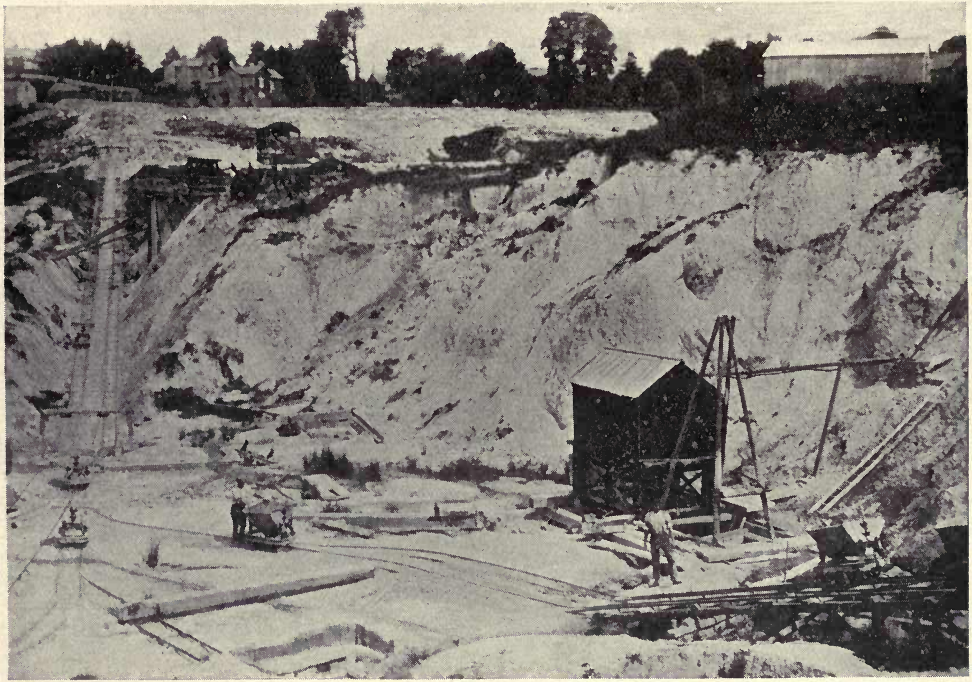


Photo by *G. C. Bishop, Esq.*

FIG. 1
TYPICAL CLAY QUARRY

contain a considerable proportion of sand and other impurities, and are not of much value. The better qualities are used for making bricks and Portland cement.

Ball clays are chiefly of Tertiary origin (p. 6) and occur chiefly in Devonshire and Dorsetshire. They are noted for their high plasticity and for the whiteness of the material formed when the clay is heated intensely in a kiln. In addition to this they undergo partial fusion (known technically as *vitrification*) the pores of the material being filled with this fused matter so that when the mass is cooled a remarkably strong and acid-resisting ware is produced. Good qualities of ball clays do not lose their shape by fusion until a temperature above 1600° C. (2900° F.) is reached, and this valuable combination of vitrification without loss of shape is extremely important in many branches of pottery manufacture. Although ball clays are white when burned, in their natural state they are usually grey, " blue," or even black; the colouring matter is of an organic nature and burns away in the kiln. Ball clays are extremely fine in texture, and will pass almost completely through a sieve with 200 holes per linear inch. The best qualities have a composition closely resembling that of pure alumino-silicic acid (p. 9) but containing a variable proportion of soda and potash. They may, therefore, be regarded as pure clays in which a small portion of the acid has been combined with alkali; this accounts for their vitrification combined with ability to resist very high temperatures without loss of shape.

The chief uses of ball clays are for pottery—in which they constitute the chief plastic ingredient—and as a bond for uniting less plastic materials into a plastic mass.

Boulder Clays are those which form part of the Glacial Drift (p. 4) which is the material immediately below the soil over the greater part of the North and Midlands. The term is used to include all the plastic portions of the deposit so that boulder clays are usually very impure and contain large proportions of sand and stones. Sometimes boulder clays are seriously contaminated with limestone particles, which destroy any goods made from such clays.

Boulder clays are usually highly plastic, but are too impure to be used for high-class pottery; they are extensively employed in the manufacture of bricks, tiles and coarse ware.

Brick Clays are usually impure mixtures of clay and sand or chalk. When very loose and friable in texture the sandy clays are termed *loams* and the chalky clays *marls*. The more plastic clays are known as *strong clays*, but if excessively plastic and so unusable for brickmaking they are regarded as *foul clays*. Clays which are deficient in plasticity are termed *lean clays*.

Most brick clays contain sufficient iron oxide to produce red bricks, but those which also contain chalk or to which chalk is added in course of manufacture, form white bricks. If the proportion of iron in the clay is very small or if it is in the form of coarse particles of iron sulphide (*pyrite*), buff bricks will be produced; the lower grades of fireclay are of this nature.

Brick clays which are sufficiently lean to be used without admixture and with very little preliminary treatment are frequently known as *brick earths*, but they do not differ in any other respect from the other kinds of clay used for brickmaking.

Brick clays do not form a distinct class, as any clay which can be made into bricks may be so termed; hence clays from almost every geological system are legitimately termed brick clays, and the composition of the clays used for this purpose is therefore too varied to admit of any definite statement concerning it. It is important to observe that pure clays are not suitable for brickmaking, and would not produce the pleasing colours for which some brick clays are so famous. These colours are largely due to the iron compounds present in the clay; whilst the lime, alkalies, and other materials effect a partial fusion and usually give added strength to the bricks. A further range of colours is also produced by the action of the fuel and kiln-gases on the impurities in the clay; thus the blue bricks of Staffordshire owe their colour to the reduction of the iron compounds they contain, whereby a dark coloured fusible compound is produced which, when cold, forms bricks of remarkable strength.

Cement Clays are used in the manufacture of Portland and similar cements. They are usually alluvial in character and preferably contain a considerable proportion of chalk or limestone dust. Shales (p. 26) are also used for the same purpose (Chap. XIX).

China Clays are those used in the manufacture of china ware and other forms of porcelain, but as they are among the purest clays, they are also employed for a variety of other purposes, including the manufacture of paper and as a filling or diluent of various chemical preparations, toilet powders, etc.

China clays are also known as *kaolins* and as *porcelain clays;* they are found almost exclusively in Cornwall and Devonshire (so far as Great Britain is concerned), but materials closely resembling china clay, yet occurring in different geological formations and possessing certain distinguishing properties, are found in Europe, China, United States and in various other parts of the world. The true china clay of Cornwall and Devonshire occurs irregularly mixed with the decomposed granite of those localities and must be removed by some process of purification (Chap. VI) before it is fit for use.

The china clays of commerce usually consist of about 90 per cent. of alumino-silicic acid (p. 9) and 10 per cent. of mica and other impurities, including a small proportion of silica; the best specimens are regarded as consisting almost entirely of pure clay.

China clays are perfectly white when sufficiently pure, but inferior qualities are slightly cream coloured. They are only feebly plastic and thus present a marked contrast to the ball clays (p. 14) which most nearly resemble them in composition. When china clay is heated to a dull red heat it loses water and behaves precisely like alumino-silicic acid (p. 9), except that it begins to fuse at a temperature lower than that of the pure acid on account of the mica, free silica, etc., it contains. The burned material is so deficient in vitrified matter (owing to the absence of lime, soda and potash and other metallic oxides in appreciable quantities) that it is readily crushed. For use in pottery manufacture the china clay must, therefore, be mixed with a more fusible material such as felspar, calcined bones, etc. The chief function of china clay in the manufacture of pottery is to produce a white body which is not very sensitive to sudden changes in temperature, and its leanness and resistance to heat make it valuable for this purpose.

Under a powerful microscope, china clay is seen to consist chiefly of irregular shaped particles, together with a few lamellar plates characteristic of *kaolinite* and others indicative of mica. It is, however, erroneous to consider that china clay and kaolinite are identical; as the former is amorphous and the latter crystalline, though the clay particles are usually so minute that it is seldom possible to state definitely whether they are crystalline or not.

Fireclays are those which are sufficiently refractory to show no signs of fusion when heated in a steadily increasing temperature to 1;580° C. (2,876° F.) though the term is commonly restricted to clays of this character found in association with coal and not to the china and ball clays. The Coal Measure fireclays occur in all the large coalfields in commercially valuable quantities, and are largely used in the manufacture of bricks for furnace-linings and other refractory purposes, as well as for the manufacture of sanitary ware, glazed bricks and other materials where a glaze free from lead, of high melting point and great resistance to acids and atmospheric influences is required. Such glazes cannot be burned on clays which are not refractory, as the clay would lose its shape at a lower temperature than that at which the glaze will fuse.

Fireclays occur in the form of a soft rock which requires considerable force to crush it. They become plastic when the crushed clay is mixed with water; but are not plastic when mined. In composition they appear to consist of alumino-silicic acids, which are richer in silica than the composition mentioned on page 9, and usually contain between 50 and 70 per cent. of silica in combination with 20 to 28 per cent. of alumina. Their composition is, however, so variable in different localities that it is difficult to represent them by any chemical formula. In addition to the alumino-silicic acid present, fireclays contain small proportions of iron oxide and sulphide (*pyrite*), lime, magnesia, potash and soda ; the total amount of these should not exceed 5 per cent. (and should usually be far less) in a good fireclay, or the material will not be sufficiently heat-resisting; clays which contain more impurities are of little value for the purposes for which fireclays are employed. Some fireclays contain a variable amount of free silica which also reduces their refractoriness (p. 25); this silica must not be confused with that combined with the alumina and forming the clay proper. Small proportions of organic matter give fireclays a grey colour but, on burning, this is destroyed and a buff or stone-coloured material is produced; the uniformity of the colour is commonly spoiled by spots and patches of a darker colour due to the effect of the heat on the iron compounds present, though the proportion may not be sufficiently large to interfere seriously with the refractoriness of the clay.

Kaolinite is a crystalline mineral occurring in many clays in small proportions and occasionally found alone. In chemical composition it is an alumino-silicic acid, and on analysis yields the figures mentioned on p. 9. Its crystalline nature distinguishes it from clays, though otherwise it is so closely related to them that for many years it was regarded as typical of pure clay. Being crystalline it is necessarily devoid of plasticity, and it is of no commercial value, being chiefly interesting on account of the coincidence between its composition and that of the kaolin (china clay) from which it derives its name.

Marls are natural mixtures of chalk and clay, but the term is also used for friable clays which are devoid of chalk. This double usage is confusing.

Ochre is a fine clay rich in iron compounds, to which it owes its colour and distinguishing properties. It is chiefly used as a pigment, and may be well imitated by mixing ferric oxide with a white clay such as china clay. When heated carefully to dull redness it forms *burnt sienna*—a pigment first made by thus treating the ochre found at Sienna.

Pipeclays are clays suitable for making clay tobacco pipes, but the term is applied to all white clays, and therefore includes china clay and some ball clays as well as a number of impure clays which burn white at a moderate temperature yet are too fusible to be classed with either of the foregoing. The leaner varieties of pipeclay are largely used as a mild abrasive for polishing metals and for whitening leather, etc.

Plastic Clays are those in which the property of plasticity is sufficiently developed to be noticeable, so that the term "plastic" is used quite independently of the composition of the clays. The most plastic clays are those described under *ball clays* (p. 14), whilst the *china clays* may be regarded as possessing the least plasticity of the relatively pure clays.

Plasticity may be defined as the property which enables a material to be pressed into any desired shape and to retain that shape indefinitely when the force producing it has been removed. It is this property which makes clays so valuable for modelling and for the manufacture of pottery of all kinds, and in many ways it distinguishes clays from all other substances. Some others are plastic under special conditions—as glass when at a red heat—but no natural substance of a mineral character is so plastic as clay, and few, if any, artificial materials possess as much true plasticity.

The plasticity of clays appears to be a physical rather than a chemical property, though the relation between the chemical constitution and the plasticity of clays has been studied for so short a time that it is impossible, at present, to make any definite statement regarding it. So far as present knowledge can show, the plasticity of clays is due to their peculiar power of retaining or combining with water. A clay which is perfectly dry is never plastic, and it is only when the particles are sufficiently small and are very intimately mixed with a suitable proportion of water that the material becomes plastic. Hence, all investigations as to the cause of plasticity are made with a view to learning whether the water enters into a physical or chemical combination with the clay. One widely accepted view is that the water combines chemically with the clay, converting it into a jelly-like substance to which the term colloidal (from *kollos*, glue) is commonly applied. It is characteristic of all colloidal substances that they swell when in contact with water, and that they absorb water in a form which is different from that in which a sponge absorbs it. When dried, the absorbed water is driven off and the substance then shrinks in volume and becomes somewhat hard and horny. A further characteristic property of colloidal substances is the manner in which they can remove dyes from a solution, leaving a colourless fluid, whilst the colour cannot be removed from the colloid by any washing process. These and various other properties of colloid substances are possessed by plastic clays, though the view that clays are colloids does not explain all the facts. This may be due to insufficient knowledge of the facts, and there is a great probability that the colloid theory will play an important part in the explanation of the cause of plasticity, even though it may require to be supplemented by other information.

There are many other explanations as to the cause of plasticity which have been suggested; one of the most probable is that the particles of clay are so small and so porous that the proportion of water they can absorb mechanically is much greater than that so retained by larger particles, and that the water which adheres to the exterior of the clay particles forms a peculiar cushion which enables the particles to move freely over each other when subject to pressure, and yet is sufficiently adhesive to prevent them losing their new positions when the pressure is removed. This purely mechanical theory accounts well for the plasticity, but it does not explain many of the other facts known about clays. A similar remark is applicable to all other published theories as to the cause of plasticity in clays.

When a plastic clay is dried it loses its plasticity, but unless it has been overheated, the plasticity will be restored on again mixing the clay with water. If the plastic clay is heated to a temperature of 300° to 500° C., or above, the plasticity is destroyed permanently and cannot be restored; in all probability the constitution of the clay has been changed by the heat, the constituent atoms being then re-arranged so that a restoration of the original grouping may be impossible. Hence a clay which has been burned in a kiln cannot be made plastic by any process of treatment. This change in the character of the heated material is of great importance in regard to the uses for which articles made of clay are employed.

Highly plastic clays are seldom used alone, as they shrink and crack too much in drying. This may be prevented by mixing them with a non-plastic material such as sand or burned clay (*grog*).

Potter's Clays are those suitable for making pottery, but the term is usually limited to those clays which are sufficiently plastic to be "thrown" on a potter's wheel (Chap. XVI). The best potter's clays are the *ball clays* (p. 14) with which some china clay is usually mixed to increase the whiteness of the product and to reduce the sensitiveness of the ware to sudden changes in temperature. For earthenware, and other high-class pottery, only those clays can be used which burn white or almost white, but for cheaper wares plastic clays of the nature of *brick clays* are used, the finer varieties of these being extensively employed in the manufacture of common red earthenware, flower-pots, terra-cotta, etc.

Red-burning Clays are those which are of the well-known red colour when heated to about 1000° C. They are usually plastic brick clays (p. 15) or potter's clays (p. 22) which are sufficiently rich in iron compounds to produce the desired colour. The minuteness of the particles of iron compound have an important influence on the colour of the burned clay so that no definite proportion of iron can be regarded as the minimum essential in a red-burning clay, though clays containing less than 4 per cent. of iron expressed as ferric oxide are seldom of a good red colour when burned. The red-burning clays are widely distributed, some of the best being found near Accrington, Ruabon, Reading, Corfe Mullen and Fareham, as well as in Staffordshire, Shropshire and Leicestershire. In many other districts excellent red-burning clays are found, and as a complete list is impossible of inclusion within the space here available, it is somewhat invidious to make distinctions between the clays of different localities.

Attempts have been made to improve the colour of red-burning clays by the addition of iron oxide; it is seldom that these are successful as the iron compound in the natural clays is so much more finely divided than that which is prepared artificially.

The composition of red-burning clays varies as much as that of brick clays, and it is important to remember that it is the iron compound rather than the other ingredients in the clay which produces the colour;

for this reason the chemical composition of such clays is of minor interest.

The precise composition of the colouring matter in red-burning clays is not certainly known; in the natural state these clays give no indication of the colour they will produce when burned. There is a widespread impression that the colour is due to red oxide of iron; if this is the case some other compound of iron must be present in the raw clay, and this must be decomposed on heating, as few clays are red before they are burned. Various ferro-silicates decompose on heating, with the formation of a red product, but their existence has not definitely been proved in clays.

Refractory Clays are those which are sufficiently resistant to heat to be used for furnace-linings, etc. (see *Fireclays*, p. 18). The most refractory clays are the china clays, ball clays, and fireclays, good qualities of which will not show any sign of fusion when heated at 1,600° C. (2,920° F.) whilst the best qualities will not fuse below 1,700° C. (3,100° F.). The refractoriness of a clay depends principally on the amount of pure clay it contains, but the influence of small proportions of oxides present as impurities is so great that it usually appears to be out of all proportion to the amount of impurity present. This is largely due to the fact that these extraneous oxides readily combine with the clay, forming compounds (alumino-silicates and silicates) which are readily fusible, so that the reduction of the heat resistance of the clay is not dependent on the extraneous oxide but on the compounds it forms with the clay and with any other impurities present. Thus, if two metallic oxides such as soda and lime are both present in a clay they will reduce its refractoriness more than an equal proportion of either oxide without the other. The reasons for this curious action are too complex to be discussed here.

It is a curious fact that silica is equally as refractory as the best refractory clays, yet if a mixture is made of silica and a refractory clay, the mixture will be much less refractory. The loss in heat-resistance depends partly on the proportion of the two materials and partly on the sizes of the particles—small grains producing a more readily fusible product than larger ones. The most fusible mixture of silica and refractory clay consists of 20 per cent. of clay (alumino-silicic acid) and 80 per cent. of free silica, or using the form common in analysis, is composed of 9 per cent. of alumina and 91 per cent. of silica.

Users generally expect a high grade refractory clay when made into bricks or other articles to be capable of (*a*) resisting any temperature to which it is likely to be exposed when in use, (*b*) resisting pressure put on it by the contents of the furnace or by adjacent masonry, (*c*) resisting the cutting action of flame and hot gases, including any flue dust therein, (*d*) resisting any abrasive action due to the movement of the contents of the furnace or accidental blows as from a poker, (*e*) resisting sudden changes in temperature which may be unavoidable in ordinary work and (*f*) expanding or contracting within such narrow limits that the strength of the work is not endangered.

No articles made of refractory clay can fulfil all these requirements in the highest degree; and it is therefore necessary to choose which are the more important. Thus, strength can only be gained at the expense of some refractoriness and *vice versâ*, and resistance to sudden changes in temperature is incompatible with great strength or an absence of porosity. It is in the balancing of these various opposing requirements that the skill of the clay-worker consists.

Sagger Marls are really fireclays (p. 18) the term being used almost exclusively in Staffordshire for clays suitable for the manufacture of the fireclay cases or *saggers* used by potters in burning ware, though these clays are equally suitable for many other purposes for which fireclays are used.

Shales are clays which have been hardened by pressure and by the formation of a cementitious matter between the particles so as to produce "rocks." When the cementitious matter is very extensive and other conditions are suitable, *slates* are formed. The term shale relates to the physical state of the material rather than to its chemical composition, a characteristic feature of all shales being the ease with which they can be split into thin layers or into still thinner laminae. Some shales are chiefly composed of grains of sand cemented together with a siliceous material, others consist of sand and clay similarly united, whilst others again are composed almost exclusively of clay; these last are valuable as a source of clay and are conveniently known as *clay shales*. They are simply indurated clays, and on crushing them to powder they are again converted into lean clays, which, with a suitable proportion of water, form a plastic mass very suitable for bricks, tiles and terra-cotta. Some of the clay shales burn to a particularly pleasing red colour and are, for this reason, in great demand as a material for the manufacture of the goods just mentioned. They are particularly suitable for the manufacture of large pieces, as they are not so plastic and are less tender than many clays which have not been subjected to compression. Many shales are entirely useless for the manufacture of bricks and other articles, but some of them are used as a source of mineral oil (*oil shales*) and others form a raw material in the manufacture of alum (*alum shales*), on account of the large amount of pyrite they contain.

Siliceous Clays are those with a larger proportion of silica than that needed to form the alumino-silicic acids which constitute the essential material in all clays. The term is, however, used for all clays containing more than 50 per cent. of silica, this being slightly above the proportion of that oxide in the best pottery clays. The form in which the remainder of the silica is present in siliceous clays is still open to question; in some of the fireclays almost the whole of the silica is combined with the alumina in the form of alumino-silicic acids rich in silica, but in various other clays a considerable proportion of free silica is present as sand or silt, which can usually be removed by careful washing, though the separation is never perfect.

Stoneware Clays are usually related to the ball clays (p. 14) and are sufficiently rich in fusible matter to form a strong, vitrified and impervious ware when heated to a suitable temperature in a kiln. The chief characteristic of a stoneware clay is that the ware made from it shall be impervious without loss of shape, and this can only be secured by the intimate admixture of a flux or fusible compound with the clay, this mixture being made artificially or having occurred naturally in some remote geological period. The natural clays are preferable, as the mixing is more intimate than is possible with a mechanically produced substance. The substances which produce this partial fusion or vitrification are primarily metallic oxides such as lime, magnesia, potash and soda, with iron oxide in the less pure clays. These oxides are not usually present in the free state, but in the form of compounds such as felspar, mica and other alumino-silicates and silicates.

Stoneware clays are used for the manufacture of filters, hot water bottles, chemical ware and for all pottery of a coarse character in which strength and impermeability are required. *Porcelain* may be regarded as a superfine stoneware, though this term is never applied to it in commerce.

Surface Clays are those which lie so near the surface that they can be won by simple digging or quarrying; in this way they are distinguished from the fireclays or *underclays* which have to be mined. The varieties of clays which are rightly included as surface clays is so great that the term gives but little idea of the nature of the clays, though most of them are red burning ones or white burning marls.

Terra-cotta Clays do not, strictly, form a class by themselves, though the term is conveniently used for those clays which are sufficiently uniform in composition and sufficiently lean to be used for the manufacture of large pieces. For the best ware, a terra-cotta clay should contain such a proportion of fine clay that its surface can be worked to a smooth finish which becomes vitrified and impervious when the goods are burned in a kiln. At one time it was customary to confine the use of the word "terra-cotta" to ware of a brick red colour, but similar ware made of buff-burning clay is now known as terra-cotta, and architectural blocks made of clay and covered with a glaze are commonly referred to as being made of "glazed terra-cotta," irrespective of their colour.

Vitrifiable Clays are those which form an impervious or vitrified mass when burned. As all clays will do this, if the temperature to which they are heated is sufficiently high, it is necessary to add that only those clays are regarded as vitrifiable which become impervious at a temperature below 1,400° C. (2,550° F.)

For most purposes it is also necessary that the ware should retain its shape at the temperature at which the clay vitrifies, though when clays are used as bonds in the manufacture of abrasives, etc., this is not necessary. There is an important distinction between "vitrified" and "readily fusible" clays; the former must fuse to such an extent that the mass becomes impervious to water as the pores are filled with the fused material, whilst the mass, as a whole, retains its shape. A fusible clay, on the contrary, fuses to a fluid at a temperature easily attained in an industrial furnace. The vitrifiable clays are chiefly used for the manufacture of earthenware (ball clays, p. 14), stoneware (p. 27) and electrical insulators.

CHAPTER III

PROSPECTING AND BORING

THE search for clay for a given purpose is known as prospecting, and, as the material is usually below the surface, it is necessary to seek for indications of it rather than to make a direct search. For such work a good knowledge of geology is essential, and with this and a careful search in railway cuttings, streams, hills, wells and other disturbances of the ground, it is possible to determine with fair accuracy the limits of a particular clay formation. In some cases, the simplest method is to dig deep holes in the ground and to examine the material thus brought to the surface, whilst, if the clay is very deep, it may be necessary to bore with special tools. Great care is needed in these operations to ensure the material brought to the surface being fairly representative of the whole, for even simple borings may be misleading, and, unless under more skilled supervision than is often the case, the examination of the borings may lead to seriously erroneous conclusions.

A careful record must be kept of the depth of each material encountered in digging or boring, the thickness of this material and the nature of those immediately above and below it. This information is best recorded by making a drawing showing a vertical section of the ground through which the bore-hole passes. The different materials must be kept quite separate—a very difficult matter in some cases—as a mixture of two or more in the drill may lead to wrong conclusions as to their nature or to the supposition that the deposit is much thicker than is really the case.

It is highly important that the various samples of material should be obtained from several distinct pits or borings, some distance apart, as the results from only one would be misleading if the material is irregularly distributed. Here, again, the services of a geologist are invaluable, though he must be one with a special knowledge of clays rather than of the general subject, as very few men have paid sufficient attention to the economic geology of clays. The more samples and the further apart the places from which they are taken, the greater will be the probability of obtaining a reliable report; but, as the examination of samples is a somewhat costly process, it is usually considered sufficient to take about six samples per acre and to make these samples as large as possible. Conclusions based on the examination of about 2 lbs. of clay taken from a single pit or boring are seldom valuable; if they are correct it is more by luck than good management, and many clay deposits have been condemned as valueless simply because the prospectors only tested a single specimen which did not accurately represent the bulk of the material.

It is scarcely possible to take too much care in obtaining representative samples of the material, and, though the examination of these may appear to be costly, it will afterwards be found to be far less so than the loss caused by the installation of unsuitable machinery, the attempt to use a clay for purposes for which it is not suited, and the opening up of a works on a site where there was only sufficient material to last a couple of years, yet all these difficulties have been experienced on several occasions by firms who were "penny wise and pound foolish" with regard to prospecting and the examination of the materials.

It is a curious fact that some of the most attractive clays are the most misleading to the uninitiated; thus the glacial drift clays of Lancashire are extensively used for bricks and coarse pottery, and some of them are well suited for this purpose, yet other portions of the deposit, which have a smoother texture and greater plasticity, are almost worthless on account of the fine limestone dust and pebbles scattered through them. Some other clays are highly plastic, and to an outsider would appear to be excellent for bricks and tiles, but they are useless for this purpose, because they break up when dried. The London clay is a good instance of this kind of material, for it is useless for brickmaking, except where it is closely associated with sand or chalk which can be mixed with the clay so as to deprive it of its objectionable qualities. Failure to realise this has resulted in the loss of many thousands of pounds.

Having found the clay and having learned the purposes for which it may be employed—these being preferably ascertained by an expert whose impartiality and unbiassed judgment can be relied upon—it is next necessary to decide the most suitable treatment whereby the clay can be made into the desired articles or products. Even in such an apparently simple matter as the manufacture of bricks there are several processes available, some of which are entirely unsuitable for certain clays, and failure is bound to result from any attempt to use such methods for those clays on a commercial scale. It is therefore imperative that the clay should be adequately tested as to the best method of working it before a plant is put down for that purpose. In making such tests it is equally important that they should be done by someone who has the necessary skill and appliances and yet is entirely free from any incentive to recommend the machinery or kilns supplied by certain firms. The possibilities of a biassed "expert" faking results are so great and the reward for so doing (in the form of a secret commission from the firm who will provide the machinery or kilns on his recommendation) is so much more than the fee which a prospective manufacturer will pay for testing, that too much care cannot be taken to ensure the entirely independent character of any expert's report. Whilst some makers of brick machinery are sufficiently honest to decline to supply machinery which they know is unsuitable for the clay submitted to them, there are others who are not so, and, as the purchaser of the plant is the one who will lose if a mistake is made, it is always wise for him to ensure the impartiality of the expert he employs. It is a common maxim that "a man who acts as his own lawyer has a fool as his client"; it is equally foolish for a prospective manufacturer to make his own tests of a clay, and scarcely less so for him to expect to get reliable results if the tests are carried out "gratis" by a firm of machinery makers in the hope that they will thereby obtain the order for the plant.

CHAPTER IV

MINING AND QUARRYING

For commercial purposes, clays are obtained by quarrying those which are sufficiently near to the surface and by mining those which occur at a greater depth. The choice between the two processes also depends on the nature of the material overlying the clay, on the location of the ground with respect to watershed, and on many other local conditions. Thus, the ball clays of Dorset and Devon are often worked by shallow mines in preference to open quarries, because in this way the clays are kept covered and the flooding of the workings is largely avoided; moreover, the amount of overlying material is sufficiently great to prove costly in removal, yet it is so soft that the driving of a series of shafts costs less than the removal of the whole of the over-burden.

Usually, *brick clays* and those allied to them are obtained by simple quarrying, as the cost of mining would be prohibitive, but, in some localities, clays which have been discarded by coal miners and brought to the surface of the ground in order to make more room inside a coal pit are used for the manufacture of bricks, tiles, terra-cotta, etc. Hence no general rule can be given as covering general practice. *Fire-clays* are almost invariably obtained by mining, as they are usually overlain by a great thickness of material. *China clays* are obtained by a special form of quarrying, which consists in removing the overlying material by digging, and then washing out the clay by means of a series of streams of water which flow in circuitous directions down the face of the quarry. The water, laden with clay and "sand," is allowed to settle so that the coarser impurities may be removed, and the milky fluid is then pumped to the ground level where it is subjected to further treatment in order to separate as much as possible of the materials other than clay (see Chap. VI).

In *quarrying* clay the usual practice is to employ men with spades who dig the material, throwing the overburden of useless material into wagons or barrows so that it may be removed to a tip or spoil bank, and putting the good clay into other wagons or barrows in which it is taken to the works. It is necessary to have an efficient foreman at the quarry, as the admixture of unsuitable material with the clay sent to the works may result in serious loss to the manufacturers. It is usual to find the clay interspersed with layers or masses of sand, gravel, limestone dust and other unsuitable materials, and care must be taken to keep these separate from the clay sent to the works, much ingenuity being needed in some quarries to obtain the maximum quantity of clay at a minimum of expense.

Some clays are so plastic that an admixture of sand is necessary to make them useful; in such cases the sand may be mixed with the clay in the quarry or at some early stage in the treatment of the material. If the sand occurs in the quarry or in some accessible position so much the better; otherwise it must be purchased.

Recently, the enormous quantities of clay required by some works has necessitated the use of mechanical means of getting the clay, and the use of steam navvies has met with considerable success. These large digging machines will dig and load into wagons at the rate of a ton per minute under ordinary conditions, but they require a moderately high face of clay, and cannot be used in some clay quarries because the thickness of the clay strata is insufficient. When their use is possible, the cost of working is about one-fifth of the price for digging and loading by hand.

Shales and other hard clays must usually be quarried with the aid of explosives. A hole is bored in the ground a short distance from the face of the quarry and into this hole is placed a charge of explosives. In a large works several charges may be fired in different parts at the same time. The material is loosened and may either fall of its own weight or it may be felled by the aid of picks and then placed in wagons and taken to the works.

As it is essential that the machinery should be supplied as regularly as possible with clay, it is now usual to employ mechanical haulage from the quarry to the works. The arrangement known as endless haulage, in which the wagons are attached to an endless chain or band, is the most satisfactory in the majority of cases, but in some works it is better to have a simple haulage with a single rope, only one wagon being drawn up at a time.

In *mining* clay the methods employed vary with the nature of the material. The ball clays of Devon and Dorset and some of the Staffordshire marls are mined by means of shallow shafts fitted with a simple winch-lifting gear, but the fireclays and other clays from the deeper pits are mined in a similar manner to coal. Long passages, specially ventilated, are made underground, and from the sides of these the clay is obtained by means of picks and shovels. The use of explosives is common in some mines, but is prohibited in others on account of the danger. The clays are placed in small wagons which are hauled by ponies to the base of the shaft and

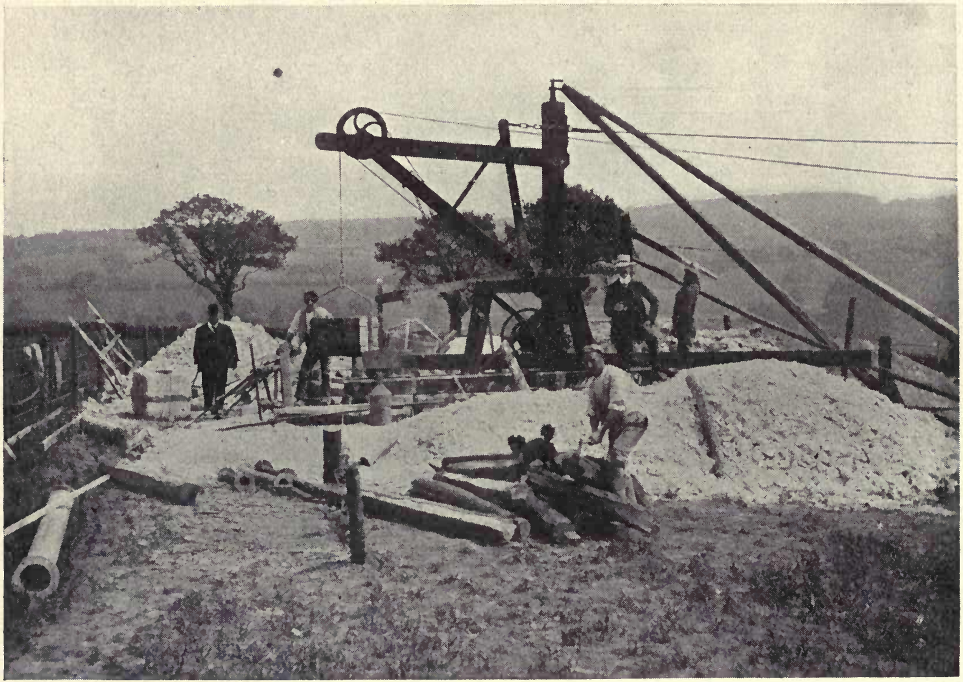


Photo by *G. C. Bishop, Esq.*

FIG. 2
MINING BALL CLAY

are then lifted to the surface by the usual winding plant at the pit-head, and are taken from thence to the works, usually by means of a pony, but sometimes by a small locomotive.

Precautions.—It is essential in mining or quarrying clay that the material should be kept as free as possible from contamination with undesirable substances which occur in close association with it. This is sometimes very difficult to secure, yet the success of the works may largely depend on the skill of the quarrymen or miners in this respect. The mixing of low grade bind or siliceous rock with a fireclay may make it useless as a refractory material, and the presence of a shovelful of limestone dust or *duff* in a wagon of brick clay may effect the destruction of more than a thousand bricks. These two instances will show how careful must be the supervision of the quarry or mine, and unless sufficient precautions are taken it will be impossible to make goods of saleable quality. Some localities are more favoured than others in this respect; thus the boulder clay deposits are particularly liable to cause trouble by limestone dust, some river-deposited clays are so irregular and uncertain in their composition as to be almost useless, and some deep-lying clays are too thin to be worked profitably. In other localities clays and shales occur in beds of such thickness that there is little or no trouble caused by adventitious materials, whilst in still other districts the only way to make satisfactory goods is to use a carefully compounded mixture from several different strata.

In ascertaining the precautions needed to be taken and in seeing that they are duly observed lies part of the skill of the successful clayworker—a skill which is often far greater than is commonly supposed by those unacquainted with the difficulties of the work. It is a curious and interesting fact that many clay quarry-men and miners with little or no book knowledge of geology are remarkably adept at distinguishing between different kinds of materials under conditions of lighting which would baffle some of the most learned petrologists and mineralogists.

CHAPTER V

WEATHERING

THE particles of true clay in a commercial clay are so extremely small that it is difficult to see their shape even under the most powerful microscope, but the clay as it comes from the quarry or mine is in the form of irregular sized lumps of stiff paste or rock. These are formed by the grains of material being compressed together by natural forces and, in some cases, by their being cemented together by some natural cement. In order to obtain a satisfactory material for use it is necessary to break down these lumps so as to separate the grains from each other as completely as possible. To some extent this can be done by crushing machinery, as described in Chap. VII, but such machinery can only exert pressure on the outside of the lumps, and its action can never be so complete as one which works from the interior outwards. This latter action is most effectively produced by two processes—weathering and washing. Of these the latter is too costly, except for the more valuable clays, but the action of the weather may usefully be applied to almost all clays, the exceptions to this statement being so small that in a volume like the present they may be ignored.

Weathering consists in exposing the clay to the action of the weather in order to effect its disintegration, and also to effect certain minor changes which may improve the value of the clay for working purposes. The chief action of the weather is during periods of frost following rain; the latter penetrates the clay and then freezes. In freezing, the water expands and forces the particles of clay apart from each other. This action is repeated in each succeeding frost until the whole of the material is broken up. For this action to be satisfactory, the clay must be sufficiently dry at first, and must not be subjected to too much rain, as this would form an impervious coating and would prevent the rain penetrating into the interior. The action of the frost does not extend to a depth of more than a foot from the surface, so that the best results are obtained if the material is spread out in moderately thin layers rather than tipped in a large heap.

Some clays are affected by air and sunshine almost as much as by frost, and these are broken up sufficiently by exposure to the air for two or three days in summer weather, whilst other clays require two or three years' exposure to the most severe wintry weather before their disintegration is sufficiently advanced. Clays which weather slowly are less satisfactory as regards the cost of treatment, as the amount of capital tied up in the weathering grounds is often very great. This is particularly the case with some of the more valuable clays such as ball clays.

The chief action of the weather on clays may conveniently be summarised under the following heads—

Mechanical Disruption brought about by the action of the water, and particularly by frost on the clay. This action is usually very slow, though very complete if sufficient time is allowed.

Oxidation of impurities, and especially of a cement of vegetable origin which binds the particles of some clays together. This oxidation may occur very rapidly under favourable conditions and is chiefly due to the action of the air. Some of the minerals in the clay may also become oxidized ; the red limonite stains observable in some light coloured clays are partly due to this cause.

Hydrolysis or the combination of water with some of the substances present in the clay. The effect of hydrolysis on the impurities in the clay is comparatively unimportant; on the clay its chief effect is to increase the plasticity, though the rate at which this can occur is so slow, that it is often difficult to note any change except after long periods of time.

CHAPTER VI

PURIFYING CLAYS

For the manufacture of bricks, roofing tiles and coarse pottery the clays are used as they come from the quarry, mine or weathering ground without any purification. To a large extent the same is true of the ball clays used for earthenware. China clay, on the contrary, is purified by a process of washing, and some of the more impure clays are subjected to special treatment to remove stones, and excess of sand or gravel.

There are four chief methods of purifying clays, each of which may be briefly described, the reader being left to decide for himself which he would use under any given circumstances—

Sorting or Picking is a very simple process. It consists in carefully examining every piece of clay as it comes from the quarry and picking out obvious impurities such as stones, nodules of iron pyrites, pieces of wood and other adventitious materials, etc. It must be carried out by careful and thoroughly conscientious men who are old enough to do this tedious work in a competent manner. In the case of fireclays this preliminary sorting should never be omitted; with other clays it is often considered an unnecessary expense.

Cleaning clay consists in making it into a soft paste by the addition of water and mixing in a suitable machine, followed by passing the paste through some form of sieve which will allow the small particles to pass whilst the larger ones (gravel and stones) are retained. The pressure required to force the clay through holes $\frac{1}{25}$th in. diameter is very great, so the best form of sieve is a hollow cylinder of steel the sides of which are perforated with a large number of holes. The stones and gravel are then retained in the cylinder whilst the cleaned clay passes out through the perforations. It is clear that only impurities coarse enough to be retained by the sieve are removed in this manner, so that the process is never very efficient, though extremely useful in the working of clays whose chief drawback is the presence of gravel or stones.

Washing consists in treating the clay with so much water that a cream or slurry is produced in which the clay remains in suspension whilst the sand and other coarser impurities are allowed to settle to the bottom of the washing tank. The slurry carrying the clay is then run off into another tank where the suspended matter is allowed to settle and the clear water is run off. The thick slime may be freed from a further quantity of water by means of a filter press, or the water may be removed by heating the material on a hot floor or dryer. The amount of purification which can be effected by washing depends on the extent of the treatment; if the slurry is only allowed to remain stationary for a few moments the clay will be very impure, but if several hours standing is possible the greater part of the impurities will settle out and a much purer clay will be obtained. Under no circumstances is the clay perfectly pure, as some of the impurities are so fine that they cannot be removed by this means.

In order that the washing may be effective it is necessary that the clay and water shall be very intimately mixed together; this is effected by breaking the clay into small pieces and feeding these into a circular tank (Fig. 3) with the water necessary to make a slurry. In the tank are arms or harrows which are rotated in such a manner that they break up the clay still further and cause it to mix with the water. By subjecting it to the action of these arms or to blades mounted on a shaft which behave in a similar manner, the clay is so broken up and mixed with the water that a uniform slurry is formed in which the clay and sand are both in suspension. When the blades or harrows

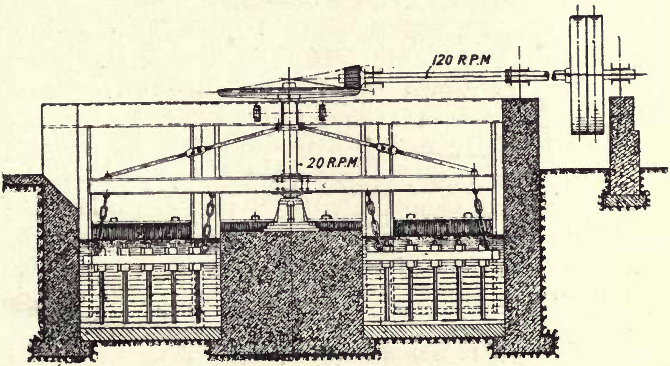


FIG. 3
WASH-MILL

are stopped, the sand begins to settle, and after what is deemed a suitable time the fluid is run off.

The clay which is washed most carefully is china clay. This is obtained (as described on p. 34) in the form of a milk-white fluid containing a mixture of clay and mica; the latter is in the form of minute flakes which do not settle so readily as sand grains. Consequently the china clay slurry is allowed to flow very slowly down long channels arranged in the form of a huge grid, with the result that the bulk of the mica is deposited and the clay contained in the slurry which flows out of the channels is comparatively pure. This slurry is then run into large settling pits where the clay settles and the clear water is run off. The soft slimy material at the bottom of these pits is then dried on hot floors heated by fires, a stiff paste being thereby obtained. For some purposes the drying is carried still further, so that lumps of dry clay are produced.

In the South of England, brick clay is often washed to free it from stones and in order that it may be more effectively mixed with chalk, the latter being needed to reduce the plasticity of the clay and to make the bricks stronger than would otherwise be the case. Chalk has also the effect of making the bricks white in colour. The washed clay (mixed with chalk) is run off into large shallow tanks, termed *wash-backs,* where it is allowed to settle and the water is then run off. The residual mixture is allowed to dry until it is stiff enough to bear the weight of a man, when it is dug out and sent to the works. This process is very slow and tedious; it may be quickened by drying the clay by artificial heat, but that would be too costly for brick-making; it is frequently done when a similar clay (but without the chalk) is used for making coarse pottery.

Electro-Osmosis is a process invented by Count Schwerin some years ago which has never made much progress in spite of its apparent advantages. It consists in suspending the clay in water as in washing and then subjecting the slurry to the action of an electric current. The impurities in the clay settle to the bottom and the purified clay is deposited on a rotary drum in the form of a soft paste and is removed from the drum by means of scrapers. Tests of various clays have produced remarkable results, but the process is regarded as too costly for commercial use.

Various other purifying methods are in use, but are only employed to a very limited extent.

CHAPTER VII

CRUSHING AND GRINDING

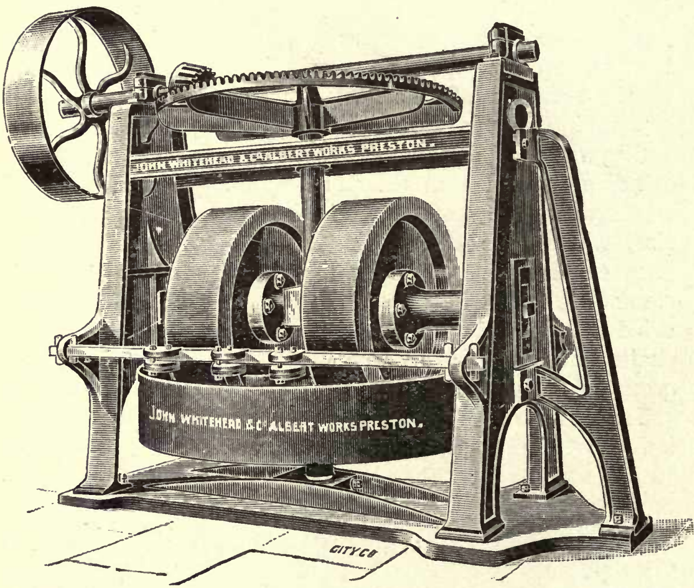
For the manufacture of bricks, roofing tiles and other purposes where a coarse clay is required, the material from the quarry, mine or weathering bank is reduced to the necessary fineness by some form of crushing or grinding machinery.

Clayworkers distinguish between crushing and grinding inasmuch as they employ the first term for the breaking down of a material into pieces of a smaller size, whilst the latter is invariably used with reference to the production of a powder. Plastic clays cannot be reduced to powder unless they have been dried and their plasticity placed in abeyance, but shales and other hard clays (such as fireclays) can be ground to powder of almost any desired fineness.

The usual method of crushing a plastic clay is to pass it between two horizontal rollers, placed side by side in such a manner that the clay falls on top and is drawn between the rotating rolls and is crushed to a thin sheet. If the clay contains stones which it is not considered necessary to remove, it may be necessary to use two or even three pairs of rolls placed one above the other, the uppermost pair being placed about 1 in. apart, the middle pair about $\frac{1}{8}$ in. apart, and the lowest pair almost touching each other. In this way the material is gradually reduced by the rolls into a series of thin flakes. Very difficult clays are sometimes subjected to the action of an edge-runner mill which consists of a pair of grinding stones running on a pan-like base.

After the stones have crushed the clay, it is drawn by scrapers over a perforated part of the pan, and at the next turn of the rolling stones it is pressed through the perforations to the crushing rolls beneath.

Care is needed with plastic clays that the material which has passed between the rolls is sufficiently thin



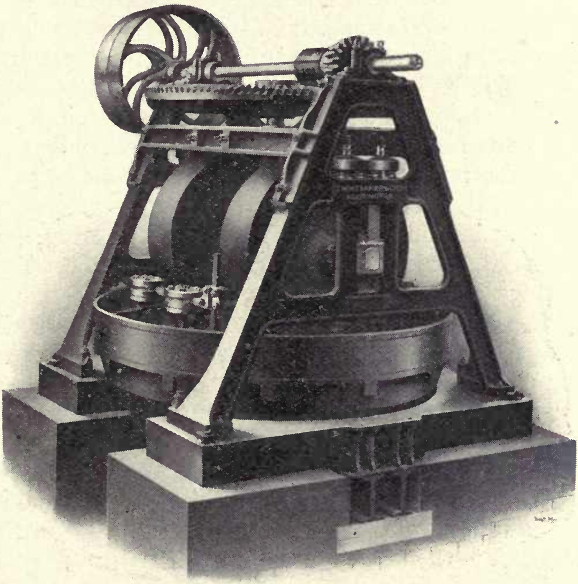
By the courtesy of *Messrs. John Whitehead & Co., Ltd.*

FIG. 4

EDGE-RUNNER MILL WITH REVOLVING PAN

and broken up to mix readily with water when treated as described in the next chapter. Unless this is done it will be difficult to produce a material of sufficient uniformity.

Shales, fireclays and other hard clays are preferably ground in an entirely different manner. One of the most suitable types of machinery for this purpose is an edge-runner mill, which consists of a pan in which a pair of grinding stones rotate on their circumference—whence the name of the mill. These runners are usually 4 ft. 6 in. to 5 ft. 6 in. diameter, the pan being



By the courtesy of *Messrs. C. Whittaker & Co., Ltd.*

FIG. 5

EDGE-RUNNER MILL WITH REVOLVING PAN

about 11 ft. diameter ; the runners may be mounted on a horizontal shaft connected to a crown wheel and pinion so that they are driven around the pan, or they may be mounted loosely on a fixed shaft and the pan driven at a moderate rate, the friction between the pan, the clay and the runners causing the latter to revolve. The former arrangement with a fixed pan is not used so much as formerly, except for very hard materials, as the output of the revolving pan is much greater in comparison with the driving power required. In order to obtain good results, the runners must be suitable for the material to be ground, the pan must be driven at a suitable speed, and the shaft carrying the runners must be free to move up and down so as to allow the runners to press with their full weight on the material. It is also essential that the quantity of clay on the pan shall be as constant as possible, for if there is too much clay the mill will not grind properly, and too little material will obviously prevent the mill working at its full capacity. To secure a steady supply of material, some firms use automatic feeders with advantage and economy.

As the material on the pan is crushed by the action of the runners, it is moved by scrapers into a portion of the pan which is perforated with slots or small holes through which the crushed particles pass into a container below the mill. Any particles which have not been crushed sufficiently small to pass out of the pan are carried forward and again pass beneath the runners and are subjected to a further crushing. The action of the mill is therefore quite automatic when once the material is on the pan.

The material which passes out of the mill will contain particles of all sizes less than the width of the slot or hole in the pan. It is not advisable to have these slots or holes too small (about $\frac{1}{8}$ in. is the usual minimum), as they would wear away too rapidly on account of the grinding action of the material. It is therefore necessary to employ some form of riddle or screen in order to separate the coarser from the finer particles of ground clay. The material of which these screens is usually made is a coarse wire gauze having 12 to 20 meshes per linear inch, but a much simpler arrangement is a sheet of steel placed at an angle of about 45 degrees and perforated with $\frac{1}{8}$ in. holes. The angle at which the plate is fixed converts it into a sieve with the effect of much smaller holes than it actually possesses, so that the wear is slight and there is so little resistance to the flow of the material over the metal that a large output is obtained. When a gauze screen is used it is necessary to vibrate it mechanically in order that the particles may hop over the cross wires and so travel down the screen; this is effected by a simple form of crank or by a loosely-hung bar, which raps the framework of the screen at frequent intervals.

The material which is too coarse to pass through the screen, travels over its surface from one end to the other, and finally drops down a chute and back to the edge-runner mill for further grinding. The finer particles pass through the screen and are received on a floor or in a hopper; they should be of a convenient size for the goods to be made from them, a coarser or finer screen being used according to the sizes of the particles desired.

This method of grinding reduces the clay to a moderately fine powder, the particles of which will unite together under moderate pressure, but will not form a plastic mass until water is added to them. This is a great convenience, as it enables a much smaller quantity of water to be used than is contained in some plastic clays.

There are many details which require care and attention in order to grind or crush clays efficiently and at the lowest possible cost; these are beyond the scope of the present volume, and for further particulars some of the larger technical works on the subject (such as those mentioned in the Appendix) should be consulted.

In some branches of clayworking it is necessary to grind materials other than clay, such as old bricks (*grog*), cement clinker, etc. For these it is sometimes necessary to use other types of grinding plant, such as disintegrators, ball mills, tube mills, etc. The screening devices for some of these materials must be capable of dealing with much finer powders than the ones described, and air-separators, which work on the centrifugal principle, are largely employed.

CHAPTER VIII

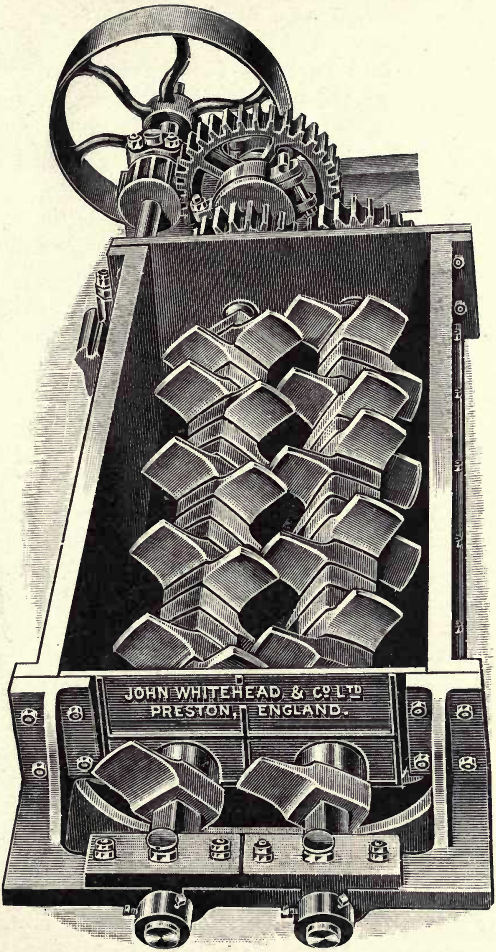
TEMPERING AND PUGGING

When articles are made of plastic clay it is usually important to treat the clay in such a manner that its plasticity is as uniform as possible, as otherwise the goods will vary in size, and this may prove extremely inconvenient. In order to ensure this uniformity of texture, the clay and any other materials which may be mixed with it must be *tempered* with sufficient water to convert it into a paste of the desired consistency.

There are two common methods of mechanically tempering clays; one consists in mixing the clay in a special form of edge-runner mill, and the other involves the use of a pugmill; the latter method is often known as *pugging*. What is sometimes termed "hand-tempering" consists in wetting the clay, then digging it and turning it over repeatedly with a wooden spade, or in using the hands to mix the water and clay together, pieces of the mass being broken off, turned and put back into the mass an indefinite number of times until the paste is uniform in texture. If the paste is very stiff it is sometimes cut into thin slices by means of a tightly-stretched wire; these slices are then re-arranged and put together to form a fresh mass which is beaten until it is homogeneous. This process—termed *wedging*—is repeated frequently until the mass is homogeneous. For small quantities, hand-tempering is satisfactory and gives very good results, but it is too costly for large outputs, and is also very laborious. The labour may be reduced by using the feet instead of the hands, the wetted clay being placed on a smooth floor and trodden by the naked feet of the workmen, who use their toes to work and knead the paste, but even this method is confined to a limited class of goods on account of its cost.

Mechanical tempering in a pan-mill is particularly efficient, but rather costly. The mill used for this purpose is an edge-runner mill with a solid revolving pan, similar in many ways to the mill used for grinding clays (Fig. 4), but of much lighter construction. Moreover, the runners are so arranged that they do not press with all their weight on the material in the pan, but only apply sufficient pressure to ensure the material being thoroughly mixed. The mills used for "grinding" mortar are a well-known type of tempering mill, but those used in clay-works are usually of better construction and more thorough action. A suitable quantity of the clay and water is placed in the mill, and the latter is then set in motion for fifteen to thirty minutes, after which the speed of the mill is reduced and a shovel with a long swivelled handle is used to remove the paste from the pan. Some pan-mills are provided with a continuous acting device, some of the material being removed from the pan in a steady stream, whilst a fresh supply of material enters near the centre of the mill. These continuous mixers have a much larger output than the intermittent ones, but their operation is not nearly so thorough and, unless the material is easily mixed, the product is not so uniform.

Arrangements of scrapers on a revolving frame are occasionally used when a very soft or friable paste is required, but to secure as perfect a union of the clay and water as can possibly be prepared, the pasting and rubbing action of the pan-mill is essential. Hence,



By courtesy of Messrs. John Whitehead & Co., Ltd.

FIG. 6

TROUGH-MIXER

though a pan-mill is costly to operate, it still remains the best machine where an entirely homogeneous paste is required. Unfortunately, it is too costly for many purposes, and it is then replaced by a pugmill or trough-mixer.

When a moderate degree of uniformity is sufficient, or where the clay is one which can be readily converted into a paste of the desired consistency, a *trough-mixer* (Fig. 6) or a *pugmill* (Fig. 7) may be used. These are really two forms of the same machine, the trough-mixer being merely a pugmill with an open top. It is less powerful in action than a pugmill, but is much cheaper to construct and is more convenient to use, so that it often forms an efficient preliminary mixer, the tempering being completed by the pugmill. Both the trough-mixer and the pugmill consist essentially of a case containing a longitudinal shaft fitted with mixing blades. These blades are placed at such an angle to each other and to the axis of the shaft that when the latter revolves and the machine is full of clay paste, the blades cut into the clay, turning it over and over until it is well mixed. The extent of the mixing will depend chiefly on the angle of the blades and on the length of the mixer; if the blades form an almost true screw-thread about the shaft the paste will be propelled rapidly from one end of the mixer to the other, but very little mixing will occur. If, on the contrary, the blades make no such uniform figure, the cutting and mixing power will be increased, but the rate of travel through the machine will be correspondingly reduced. Makers of these machines therefore effect a compromise and endeavour to combine the mixing and propelling abilities so as to give the best results with the least expenditure of time and power.

The solid material is fed into the mixer or pugmill

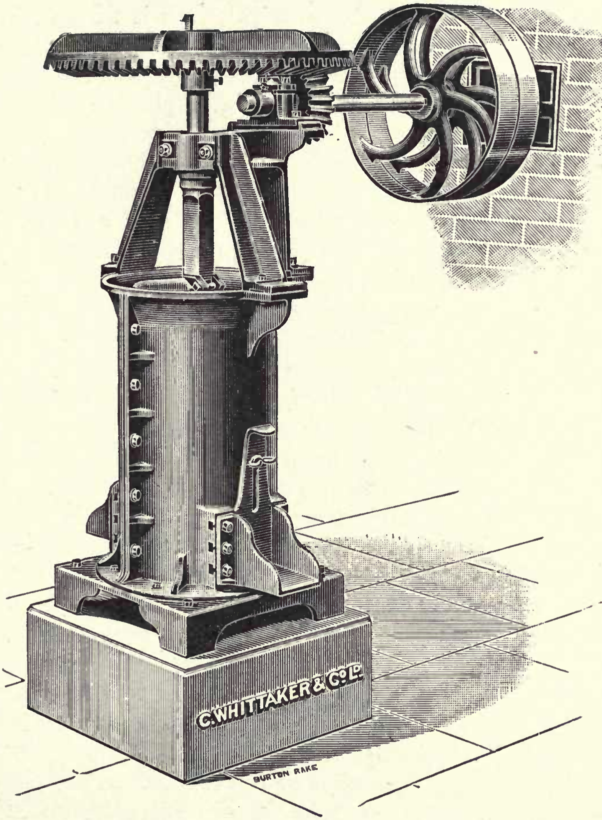


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FIG. 7

VERTICAL PUGMILL

(Fig. 7) in a small, steady stream, and any additional water required is allowed to trickle into it from a perforated pipe, it being usually necessary to employ a smart youth to adjust the water-supply so as to produce a suitable paste. By using a short length of trough-mixer, it is easy for this youth to see that the requisite proportions of solid and water are present before they enter the closed portion or pugmill. If the material issues from the mill in too stiff a form, it must be wetted still more and put through the mill again; if it is too soft it must be allowed to dry somewhat and then must be pugged over again. As both these processes are troublesome, it is desirable to see that the material is neither too wet nor too dry when it enters the pugmill. Plastic clays from crushing rolls usually require little or no added water and may be passed directly into the pugmill; dry, ground clay, on the contrary, requires a considerable quantity of water to convert it into a plastic paste, and for this reason an open mixer, about 6 ft. long, is desirable as a preliminary mixing machine.

The *consistency* of the tempered material will depend upon the purpose for which it is to be used. For hand-moulded bricks it must be too soft to handle without it adhering tenaciously to the fingers, but for modelling, or for use in plaster moulds, and for mechanical pressing, it should be so stiff that it will readily take an impression of the fine lines of the skin yet will not adhere unduly when a piece is squeezed tightly in the hand. For some mechanical presses an even stiffer paste is preferable. The consistency is largely regulated by the amount of water present in the material, but the size of the solid particles, the amount of sand and other non-plastic material and the extent of the mixing are also important.

When it is required to prepare a clay paste of the greatest possible uniformity, with the plasticity of the clay developed to the fullest extent, it is necessary to temper it several times, and in the intervals between the temperings to keep the paste in a cool place where it may "sour" without being liable to freeze. The nature of this *souring* is imperfectly known; it was at one time thought to be due to bacterial action, though this has not been proved, and it is now generally considered as a purely chemical reaction between the water and the clay. It is certain that during the process of souring the water is distributed more uniformly throughout the mass than is possible by any mechanical means yet devised, and that the plasticity of the clay is markedly increased. If the paste is kept in a hot room it dries too rapidly, and the reaction whereby the plasticity is increased is less noticeable, hence the desirability of storing the paste in a cool place.

It is considered by brick manufacturers, and by many others engaged in the production of clay goods, that prolonged storing is too costly in comparison with the results obtained, and this is probably true where the cost is of prime consideration; in the manufacture of valuable ware such as porcelain, however, the value of souring is more appreciated, particularly among the Chinese, who have been accustomed to store some of their clay pastes for several generations before deeming it fit for use for their best ware. A short storage of a couple of days or so greatly improves the working power of all clay pastes, so that where it can be done this storage is desirable, even when a longer period, though preferable, may be deemed too costly.

CHAPTER IX

CLAY SLIPS AND THEIR USES

The fluids made by mixing a clay with about an equal weight or more of water are known as *slips*, and the production of such fluids serves several useful purposes in clayworking. In the first place, materials which may occur as impurities in the clay may not be able to remain in suspension so long as do the clay particles, so that the production of a slip which is allowed to stand for some time and the fluid then run off will serve as an efficient means of removing such impurities. Such a process is known as "Washing" (p. 44).

The production of a slip is also a convenient means of obtaining a clay or other substance in a state convenient to mix with others. Thus, in the manufacture of earthenware (Chap. XV) the clay and other ingredients are all converted into slips; these slips are then mixed together, after which the mixed slip is passed through a filter-press where the bulk of the water is separated and a plastic cake is produced. By this means a much more uniform mixture is obtained than would be produced if the materials were treated as described in Chap. VIII.

Slips are usually produced from the higher grades of clay in a machine known as a *blunger* (Fig. 22). This consists of an upright drum or cylinder fitted with a vertical shaft carrying a number of arms or blades. The materials and water are placed in this blunger, and the shaft is rotated somewhat slowly at first and then more rapidly. As the blades travel round they churn up the contents and cause a thorough intermingling of solid and water whereby a slip of uniform consistency is formed. If the material in the blunger consists of a particularly tough clay, it may be necessary to run the machine for an unprofitably long time; this may be avoided by breaking up the clay into smaller pieces and putting only a few at a time into the machine.

The amount of material in a slip can be judged with considerable accuracy by weighing one pint of the slip, and potters are accustomed to make their slips to certain definite densities (expressed in terms of "ounces per pint"), so as to secure uniformity of composition for their various mixtures.

In order that a material may be made into a useful slip, it is necessary that it shall consist of small particles, like clay, or that it shall have been ground to a fine powder. Blungers have no true grinding or crushing action; they merely serve to disintegrate particles which are minute yet held feebly together by some adhesive power. Hence, felspar and other materials used in the manufacture of glazes, must be ground to powder before they are made into slip in a blunger. This preliminary grinding is usually effected in an edge-runner mill or a ball mill (Chap. VII).

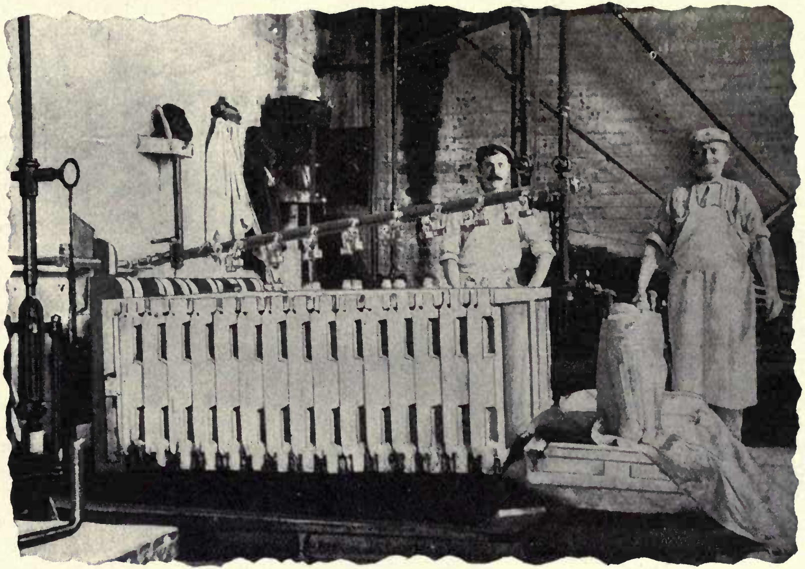
When mixtures of several clays are to be used, or where a body is to be composed of several substances, it is often convenient to make each into a separate slip with a definite weight per pint, and then to mix suitable volumes of these slips together. In practice, this is much simpler and more accurate than weighing out the corresponding weights of each material and then mixing them together. It has the further advantage that two or more clays can be mixed with great intimacy, whereas this is almost impossible when several plastic clays are tempered in the plastic or pasty state.

Tempering (Chap. VIII) is excellent for making a homogeneous paste from a single clay or from a mixture of clay with sand or grog, but, where two or more plastic clays are to be mixed into a paste and great uniformity is essential, it is better to first make each into a slip by blunging, mix the two slips together in the desired proportions, blunge the mixture thoroughly so as to secure complete comminution and homogeneity and then removing the surplus water by means of a filter-press.

A filter-press (Fig. 8) consists essentially of a series of bags of closely woven material; these bags are filled with slip and are then closed. Pressure is applied to the bags in such a manner that the water escapes through the material, but the clay is retained in the bag. After all the surplus water has been squeezed out in this manner, the bags are opened and the "cake" of paste is then removed.

An alternative method of converting a slip into a plastic paste consists in heating the slip in a large, shallow tank or pan, so as to evaporate the greater part of the water. This requires a much longer time than when a filter-press is used, but the combined effect of the heat and the time of treatment produce a more plastic paste than that formed in a filter-press. This is often important in dealing with mixtures of low plasticity as are some of those from which porcelain is manufactured (see Chap. XV).

Slips are extensively used as a convenient means of applying a coating of fine clay or glaze to an article; the latter is burned so as to make it porous and is then dipped into the slip. The water in the slip is absorbed in the pores of the article, and the solid matter remains on the exterior of the article as a thin, uniform coating. Such slips are made by grinding the appropriate raw



By the courtesy of *Messrs. W. T. Copeland & Sons.*

FIG. 8
FILTER-PRESS

materials, mixing these in suitable proportions and then with water in a blunger. In order that any coarse particles may be removed, the slip is passed through a fine sieve (termed a *lawn*) which only permits the finer particles to pass through it. It is necessary to keep such slips in a state of frequent motion by stirring them immediately before use, as otherwise the heavier particles will sink towards the bottom of the container and the composition of the slip will be made irregular. Stirring obviates this if it is performed with sufficient frequency and at the right time.

By covering an article made of a cheap clay with a thin coating of a more expensive clay it is often possible to obtain the same effect as if the article had been made throughout of the better clay. Thus, glazed white bricks are usually made of a buff-burning clay covered with a slip in which the white-burning clays predominate. Sometimes pots which are made of a very common clay are "faced" with a coating of a high grade, red-burning clay, and thus present an appearance which is superior to that which would be obtained were no such coating used. It is necessary that the slips used for this purpose should be composed of such materials that the coating has the same contraction as the cheaper clay when heated; otherwise the coating will crack or peel off and so will spoil the goods. Sand or flint is generally added to reduce the shrinkage of the coating, but the addition of Cornish stone or felspar is sometimes necessary in order that the coating may be made sufficiently fusible to adhere properly to the article to which it is attached.

Articles made of coarse clay may first be covered with a slip of white clay, as described above, and afterwards with a glaze, the latter being applied in a similar manner. The coating of fine clay is hnown as a *body* or *engobe*.

The compounding of successful slips requires great skill and experience and is an important part of the work of the successful manufacturer.

CHAPTER X

BRICKS

THE manufacture of bricks covers so many operations and includes so many processes that a large volume is insufficient to deal exhaustively with the subject; in the following pages, therefore, only the merest outline can be given of an industry which is of exceedingly great importance, and the reader who wishes for further information must consult one of the works mentioned at the end of this present volume.

Commercially, bricks may be divided into four main groups, viz., (*a*) Building bricks for architectural purposes, (*b*) Engineering bricks for bridges and other structures where exceptional strength or resistance to corrosion is required, (*c*) Glazed bricks, chiefly used in architecture, and (*d*) firebricks used for furnace linings and other structures in which great resistance to heat is necessary. The last named are described in Chap. XVII.

Clays used for Bricks.—For building bricks the clays used are generally impure; in fact, a pure clay would not prove at all suitable for such a purpose, as it would not produce bricks of sufficient strength, and the colour would be a dead white, which would soon become discoloured, as the material would be very porous. The attractive colour of red bricks is due to iron oxide present in the clay; the curious colour of blue engineering bricks is due to the same substance, but the firing of the bricks being under different conditions, a different colour is produced. The strength of bricks is largely due to the formation of a bond or cementing

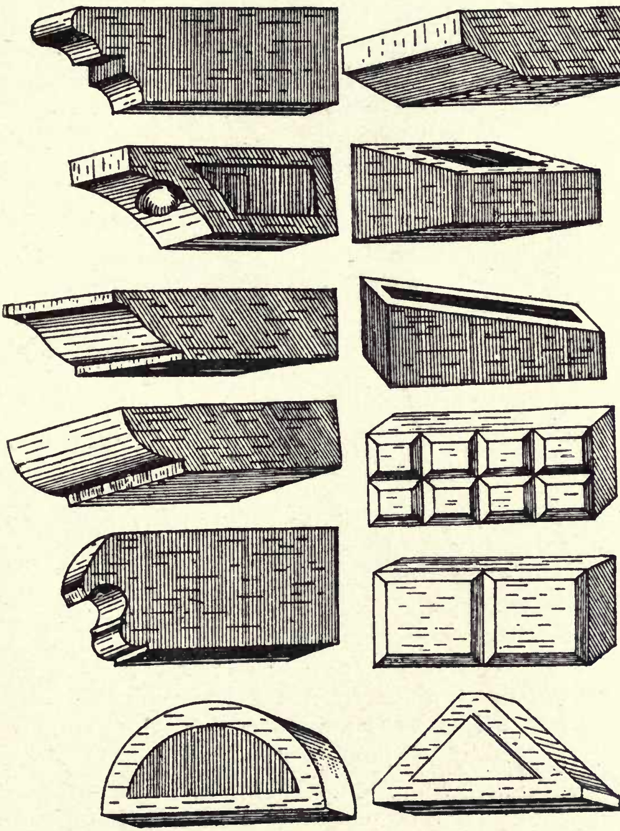


FIG. 9

FANCY BRICKS FOR VARIOUS PURPOSES

material which unites the grains together; this bond is produced by the fusion of some of the constituents of the clay or by the combination of some of the impurities with the clay itself so as to form a readily fusible compound. This fused matter, on cooling, becomes solid and holds the particles of the bricks very firmly together.

Building bricks are made from almost all the commoner varieties of clay (see page 15), either alone or mixed with some material to confer special properties on them. Thus, *London Stocks* are made from a mixture of chalk, cinder dust and clay; this forms a mixture which is less plastic than the original clay. The chalk provides one ingredient which combines with the clay and forms a fusible bond, whilst the cinder dust forms a fuel which is mixed so intimately with the clay that it secures the brick being heated more intensely than if the whole of the fuel were external to the brick. The result is a brick of great strength compared with the quantity of fuel with which it is fired. *White Suffolk bricks* are made from a mixture of clay and chalk, but without the cinder dust.

Red Bricks, both *common bricks* and *facings,* are made from clays rich in iron oxide; *buff bricks* are made from clays which contain a less proportion of this oxide. *Glazed bricks* are made of fireclay and are afterwards glazed by dipping them in a suitable slip which, in the kiln, fuses and produces the glaze. Various terms are applied to bricks which are defective, such as *grizzles*, *burnovers*, etc.; such bricks are only used for the roughest work or where strength or appearance is unimportant. The best qualities of building bricks are used for exterior work, and are known as *facings*; they are selected on account of their pleasing colour, their fine texture, their strength, and the nature of their surface. In order to produce a slightly dull and roughened surface, the bricks are sometimes coated with sand, and are then known as *sand-faced bricks*. Local terms are extensively used, but the foregoing include the chief varieties of building bricks of a saleable character. There has been an increasing tendency of late to designate bricks by fancy names, such as "Rustic" bricks, "Tapestry" bricks, etc.; these names are usually registered, and often form a valuable asset to the firm which is able to build up a good business by the use of such a special title for their goods.

Preparation of Clay.—The clay used for brickmaking is usually converted into a plastic paste, but sometimes a slightly damp powder, made by grinding the dry clay or shale, is used (see p. 49). According to the nature of the clay and its freedom from objectionable impurities, the clay is either cleaned (p. 43), passed through crushing rolls (p. 47), or put direct into the mixer or pugmill (p. 56), the necessary water being added so as to make a paste of the desired consistency. If the material is too hard to be treated in this manner, it is ground in an edge-runner mill (p. 49) and the powder and water are then mixed as before.

According to the consistency of the paste produced, the process used is known as the plastic, stiff-plastic, or semi-dry process respectively. The advantage of the two latter is that the bricks require less drying than when a very soft and highly plastic paste is used; the softer paste is easier to use and does not require so much mechanical power as the stiffer ones, but the drying presents difficulties.

Making the Bricks.—The methods of shaping the bricks depend chiefly on the consistency of the material to be used. The simplest method to describe is known as the *semi-dry process;* it consists in passing the ground powdery clay through a short mixer which will distribute any moisture present evenly throughout the mass yet without causing it to become

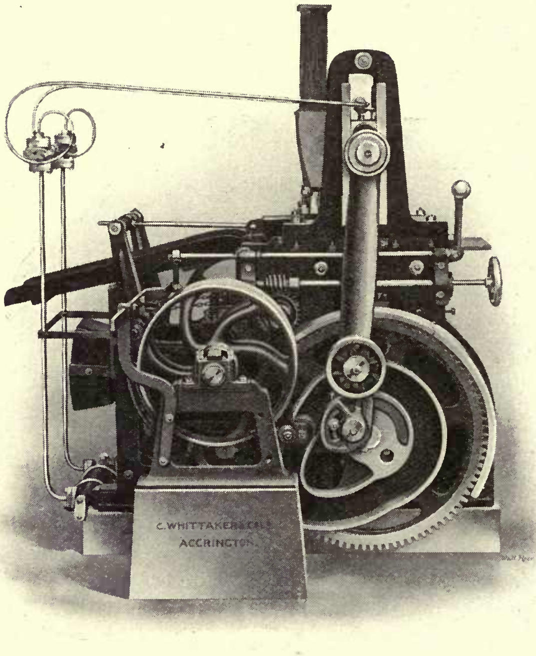


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FIG. 10

MACHINE FOR MAKING SEMI-DRY BRICKS

pasty, then into the box or die of a powerful press (Fig. 10) in which the material is subjected to the pressure of a plunger, which squeezes it to such an extent that the particles are compressed into a firm, hard brick. Owing to technical difficulties, such as the retention of air between the particles, it is difficult to produce sound bricks by this process, but by applying several distinct pressures, these difficulties are largely overcome, and with a suitable press and a material adapted to this method of working, it is possible to make excellent bricks. In the Peterborough district this semi-dry method has been used for years with great success, the material there being one of the few which are suitable for this process.

The Hand-moulding Process is next in simplicity;

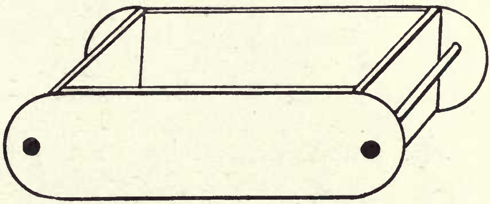
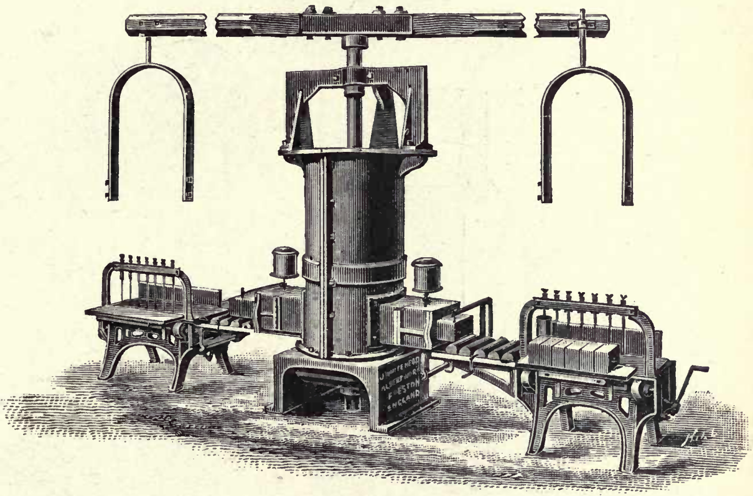


FIG. 11

MOULD FOR HAND-MADE BRICKS

in it, a plastic and rather soft paste is used. This is placed on a wooden bench of convenient height, a sufficient space being left for the mould (Fig. 11), which is a rectangular box without top or bottom and slightly larger than a brick. The moulder dips the mould in water and may then dip it in sand; he then places the mould on the bench and takes up a mass of the soft paste in his hands and rolls it into a solid lump on the previously wetted or sanded bench. He then lifts this *clot* high above his head with both hands and throws it with great violence into the mould, filling the latter completely. The moulder then presses the paste well into the bottom corners of the mould with his fingers, and afterwards cuts off any superfluous paste from the mould by drawing a tightly stretched wire across it. Some men prefer to use a straight piece of wood, which they term a *strike*, and to scrape off the superfluous paste with this; the latter method is distinctly quicker when it can be used. With a quick turn of his wrists, the man then turns the mould with its contents on one side; and he then empties the mould on to a small board or places it on a rack, from whence it is carried away by a boy and emptied on to the drying floor. If the maker turns out the brick on to a pallet board, the carry-off boy places a similar board on the brick, and spanning both boards with his fingers without either squeezing the brick or allowing it to fall out, carries it away to the drying floor, on which he sets it carefully so as not to produce a misshapen brick. A good maker will produce 5,000 bricks a day with the aid of one strong youth and two boys.

The amount of skill required to make bricks by hand at a sufficiently rapid rate is much greater than is usually supposed, and, as the pay is small and the work both onerous and laborious, the number of hand-moulders is never equal to the demands of the trade. Consequently it has become customary to adopt various mechanical devices in order that youths and unskilled men may be employed at this part of the manufacture. The machines which imitate hand-moulding have never met with much success, as they necessarily depend on the material being capable of being pressed uniformly into the mould, whereas it is extremely difficult to fill a mould properly with a soft paste by means of any mechanism. Where a paste is moderately sandy these "soft mud machines" have proved fairly satisfactory for the production of common bricks; they usually consist of a pugmill placed above a series of moulds in such a manner that the paste is passed directly from the pugmill to the moulds. The machine is stopped momentarily whilst a wire is drawn across the top of the moulds so as to cut off the superfluous clay. The moulds are then removed and replaced by others, so that a fresh set of bricks is being made whilst the first set are being turned out of the moulds.



By the courtesy of *Messrs. John Whitehead & Co., Ltd.*

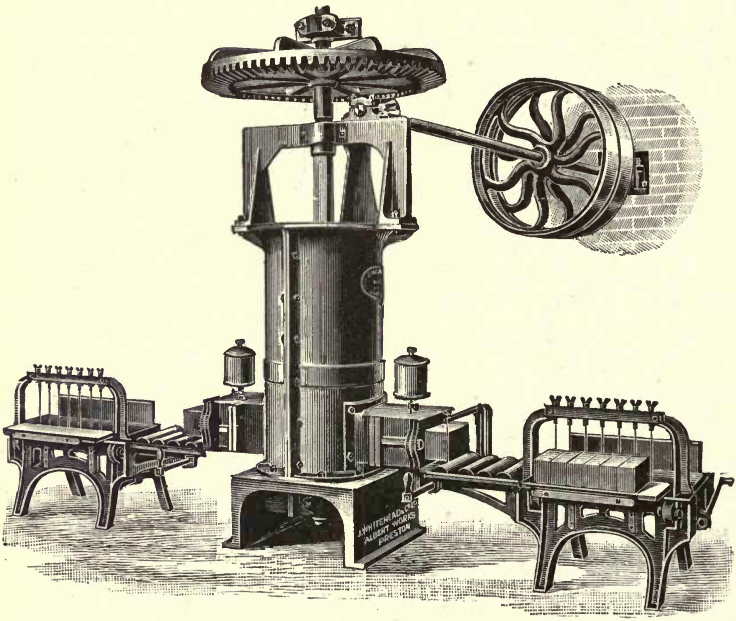
FIG. 12

HORSE-DRIVEN MACHINE FOR WIRE-CUT BRICKS

Wire-Cut Bricks[1] are made from a soft, plastic paste by an ingenious and simple process which consists in

[1] Messrs. John Whitehead & Co., Ltd., were among the earliest makers of machines for bricks of this kind, and Fig. 12 is interesting on this account. This type of machine is still extensively used where engine power is not available. The present fashion is in favour of a horizontal pugmill in place of the vertical one shown, the bricks now issuing from only *one* end of the machine.

making the exit of the pugmill (p. 56) of such a shape that the paste extruded from it is in the shape of a column or band of clay-paste whose width is equal to the length of the brick and whose height is that of the brick to be made. Hence, by cutting this column into



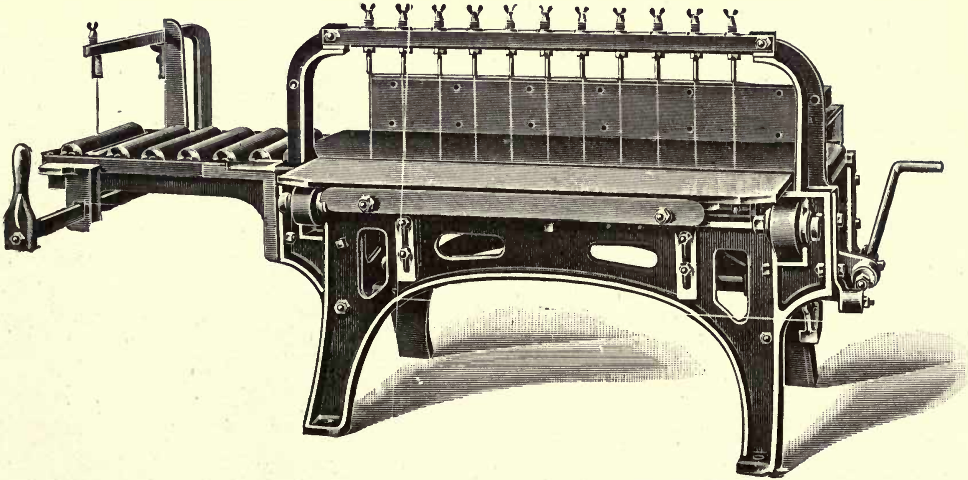
By the courtesy of *Messrs. John Whitehead & Co., Ltd.*

FIG. 13

ENGINE-DRIVEN MACHINE FOR MAKING WIRE-CUT BRICKS

pieces, each the width of an ordinary brick, it is easy to make as many bricks as may be desired. In the United States it is customary to make a longer and narrower column and to cut off the bricks lengthwise, but in other respects the process is that used in Great Britain. Small, but important, alterations in the pugmill are necessary when the clay paste extruded from it has to pass through an opening of special shape, as it is necessary that the paste shall be more consolidated than in an ordinary mixing pugmill. The column must be received on rollers or on a well-greased plate, as any resistance imposed on its movement will cause distortion of the bricks. There are many devices available for cutting the column into bricks, and some of them are very ingenious and almost automatic. It is usual, however, to employ another arrangement (Fig. 14), whose chief recommendation is that it is simple and does not soon get out of order, namely, a frame across which wires are stretched in a vertical direction above a fixed base or table. This is placed parallel to the issuing column of paste, and at suitable intervals a sufficient length of the latter is cut off by means of a tightly-stretched wire, and is pushed by hand until it is close to the wires. A mechanical pusher, operated either by a hand-lever or by gearing, is then set in motion, and this pushes the column of paste at right angles to its original direction and past the wires in such a manner that it is cut into a suitable number of bricks. The process of pushing the paste against the wires rather than the wires against the clay is technically bad, and results in ragged edges and corners; much better results can be obtained by the use of a travelling cutting table with a movable frame in which the wires actually cut the material, though the latter has never become popular in England; whilst the former is only made by British firms.

The wire-cut bricks are simply rectangular clots the shape and size of a brick; it is impossible to make them very accurate in shape, though it is remarkable



By the courtesy of *Messrs. John Whitehead & Co., Ltd.*

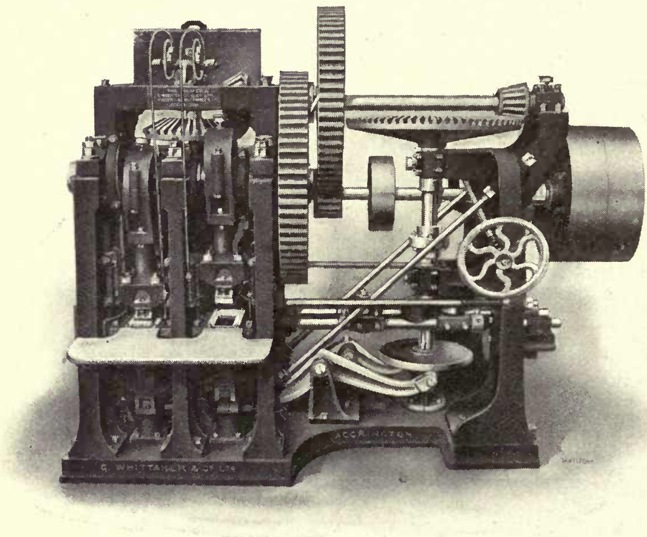
FIG. 14
CUTTING TABLE

how well they look when built into a wall. They are relatively heavy, though this may be overcome by perforating them—a process which does not add to the cost, as it is done by inserting bars in the mouth of the pugmill.

The wire-cut process is excellent for plastic materials which are too soft to be worked by the stiff-plastic process, and there is scarcely a clay which cannot be worked by one of these two processes cheaper than by any others. The semi-dry process is generally the cheapest of all where the output is sufficiently large, but it can only be used for a very limited number of hard clays. When wire-cut bricks are required to be specially accurate in shape, they are pressed as described on p. 81.

Expression Rolls are used to facilitate the manufacture of wire-cut bricks from materials which are difficult to use. They consist essentially of a pair of rollers placed one above the other and at such a distance apart that the column of clay coming from the pugmill is drawn and rolled into the desired shape before it passes through the mouthpiece or die which gives it its final shape. Pastes which would crack if made in a wire-cut machine may be worked successfully by the use of expression rolls, and these appliances have, therefore, met with great popularity in the past, though they are now somewhat overshadowed by the stiff-plastic process. So far as the more plastic clays are concerned, however, their popularity is well deserved. Usually one pair of expression rolls is sufficient, but in special cases three or more pairs, arranged so that the paste passes successively through them, have proved entirely satisfactory. These rolls do not change the shape of the clay paste so suddenly as the ordinary wire-cut machine, and their success is largely due to the gentle treatment of tender clays which is possible with their aid.

Stiff-Plastic Bricks are made of a paste which is stiff enough to require the application of considerable pressure before an indentation can be made in it. The

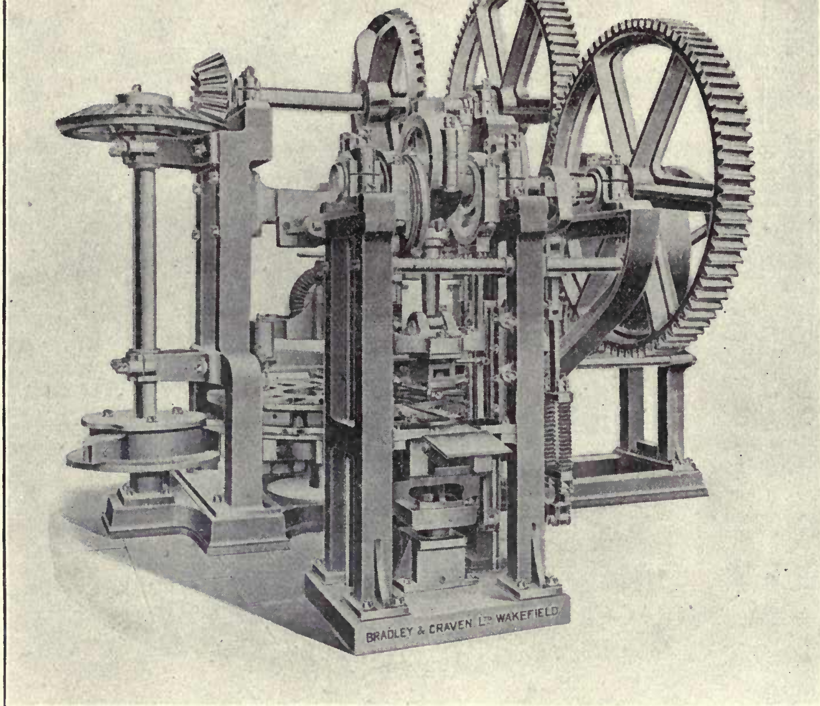


By the courtesy of *Messrs. C. Whittaker & Co., Ltd.*

FIG. 15

MACHINE FOR MAKING STIFF-PLASTIC BRICKS

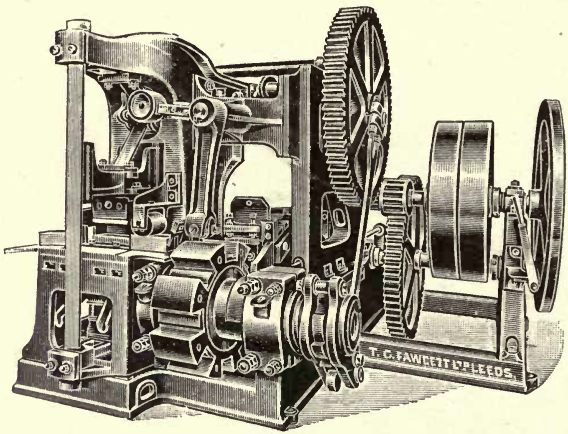
paste is usually made from a dry-ground clay, as the naturally plastic clays are usually too soft for the purpose. The mixture of powder and water is mixed in an open mixer, and is then moulded into a rough clot in the same manner as the "soft mud" bricks (p. 72), but using a more powerful compressor. The roughly-made clot is then carried mechanically until it enters



By the courtesy of FIG. 16 *Messrs. Bradley & Craven, Ltd.*

MACHINE FOR MAKING STIFF-PLASTIC BRICKS

the die or box of a press where it is subjected to a great pressure, and the brick is thereby properly shaped. The machines used for the manufacture of this class of brick vary considerably in appearance, but they all contain, as essential features, a mixer, a clot-former, and a re-pressing machine to give the brick its proper shape.



By the courtesy of *Messrs. T. C. Fawcett, Ltd.*

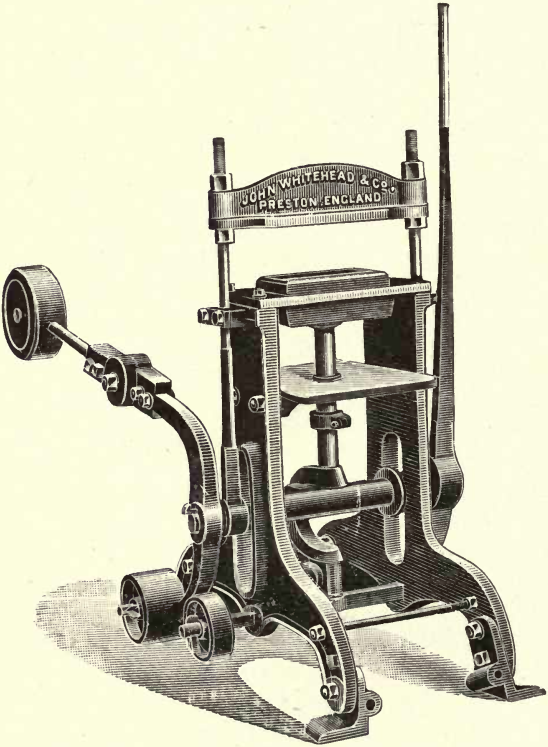
FIG. 17

MACHINE FOR MAKING STIFF-PLASTIC BRICKS

The great advantage of stiff-plastic bricks is that they are sufficiently accurate in shape to be used as facings; they can be provided with a *frog* or hollow space on one or both sides so as to make them light, and they may usually be placed directly into the kiln without the necessity of drying them. This practice is not to be recommended, as the bricks which have been dried are usually much better coloured than those which have been sent direct to the kiln. A further advantage of stiff-plastic bricks—even when they are dried—is that the cost of drying is much less than with a more plastic paste, as the latter contains a much larger proportion of water. The stiff-plastic process can only be used for clays or shales which are sufficiently dry to make a stiff paste; moister clays must be dried (which would usually be too costly), or they must be worked by one of the processes described for plastic pastes.

Re-pressing Bricks.—As it is essential to the strength and good appearance of a brickwork structure that the bricks should be as regular as possible in size and shape, it is usually necessary that the best bricks should be pressed at some stage in their manufacture. The presses used for this purpose consist essentially of a steel-lined box, the size of the brick, and a plunger which fits into the box or die and compresses the brick to the desired shape. The die is fixed, but the plunger is moved up and down vertically by some powerful mechanical device such as a lever, screw or toggle lever. Simple lever presses (Fig. 18) can only be used where a small pressure is sufficient to make the bricks accurate in shape; screw presses (Fig. 19) are highly efficient, but the large ones required for bricks are slow in action; hence, toggle lever presses are generally the best for pressing mechanically-made bricks and for all re-pressing, though some makes of cam-operated presses have proved highly satisfactory for this kind of work. Typical presses are shown in Figs. 15–19; that in Fig. 16 being operated by a cam; those in Figs. 15 and 17 by toggle levers; that in Fig. 19 by a screw; whilst that shown in Fig. 18 is a hand-operated lever press.

The bricks to be pressed should be as accurately made as possible, as any material change in their shape will necessitate a partial destruction of the texture of the brick in the press, and the original texture, if once destroyed, can never be restored. This is one

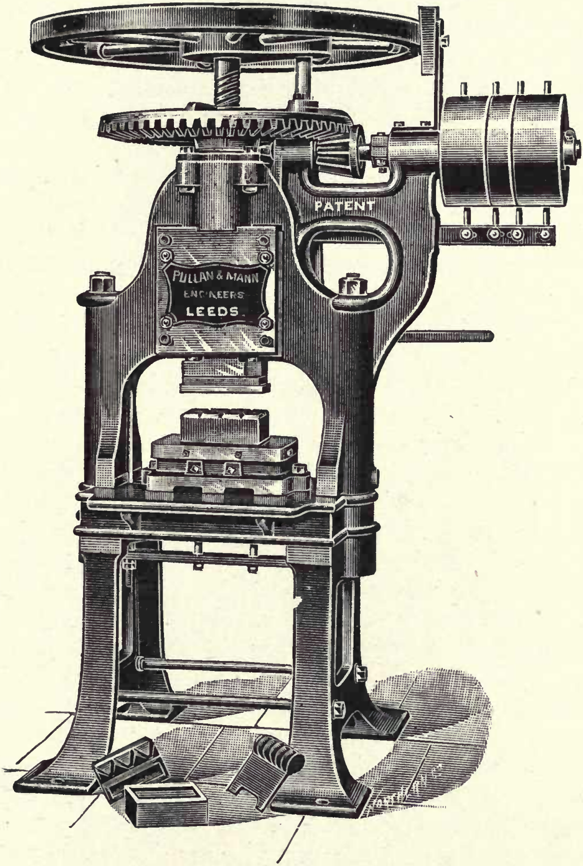


By the courtesy of *Messrs. John Whitehead & Co., Ltd.*

FIG. 18

PORTABLE BRICK PRESS

reason why many pressed bricks are weaker than the same bricks before re-pressing; the pressure exerted on the brick tends to alter its shape and make it more



By the courtesy of *Messrs. Pullan & Mann.*

FIG. 19

TILE AND BRICK PRESS (SCREW TYPE)

exact by the displacement of some of the material instead of the pressure being applied equally to every particle. The result is the formation of a series of laminations or zones of different texture and a consequent reduction in the uniformity and strength of the brick.

Bricks should be pressed when in a stiff-plastic state ; if too soft they adhere to the die and will not leave it properly, whilst if too hard they will crumble, and the pressed particles will not adhere well to each other.

Re-pressing bricks made by the wire-cut or other process in which a plastic material is used will improve the appearance of the bricks, but will not usually increase their strength. Such bricks should be pressed when about half dry.

Drying Bricks.—After bricks have been made, it is usually necessary to dry them in order that they may be burned without undue distortion. The drying may be effected in the open air, the bricks being stacked in long rows, or artificial heat may be used. The latter is commonly thought to be more expensive, but is not necessarily so, as the amount of ground occupied in the open air, necessitating the men travelling long distances with the bricks, together with the almost constant care and attention and the number of bricks spoiled by bad weather, all react unfavourably on the cost of air-dried bricks. Moreover, in a large works, where the bricks are made by machinery, open-air drying is too slow and uncertain, and under these conditions the use of a dryer becomes essential. This is the chief reason why so many attempts have been made to use materials such as the harder clays and shales, as the less the proportion of water which has to be removed, the cheaper will be the drying, and if the drying can be dispensed with altogether, as is the case with semi-dry bricks (p. 70), and sometimes with stiff-plastic bricks (p. 80), a considerable saving is effected. When it is noted that from an ordinary plastic brick no less than 1 lb. of water must be dried out before the brick can safely be placed in the kiln, it will soon be realised with what enormous quantities of water the manufacturer of 5,000,000 bricks per annum—a quite normal quantity—has to deal. The usual method of drying bricks is to place them separately on a floor which is heated from below by exhaust steam from the engine, supplemented at night by live steam from the boiler. This method is simple and convenient, but is wasteful of heat; a much more economical one is to use a tunnel-dryer, which consists of a long chamber in which the bricks are placed on a series of cars. The tunnel is heated by steam or waste kiln-gases, and the temperature is arranged in such a manner that the bricks are dried very gradually under conditions which prevent them from drying irregularly and so cracking. The tunnel remains full of cars loaded with bricks, and, at intervals of an hour or so, one car is withdrawn at one end of the tunnel whilst another car, loaded with wet bricks, enters at the other. In this way a constant succession of cars passes through the tunnel. The chief drawbacks to the use of tunnel-dryers are (*a*) the great capital outlay necessary for the structure and the cars and (*b*) the liability of the dryer to get out of order. This latter defect is chiefly due to the installation of dryers of an experimental type by men who have not sufficient knowledge of the scientific principles underlying drying or of the effect of heat and moisture on the cars, rails, etc.

Whatever form of dryer is employed, it is necessary that, at first, the bricks should be kept in an atmosphere which is almost saturated with moisture, so that they may be warmed without any drying taking place. When they are warmed through, air which is less saturated with moisture may be supplied, and, as the temperature of the bricks continues to rise, drier and still drier air may be employed. The commonest cause of damage to bricks during drying is the use of too dry an atmosphere, which hardens the outside of the brick, causing it to shrink more rapidly than the interior and thus produces cracks; by keeping the air at a suitable state of moistness the drying may be effected rapidly and with little or no risk of damage to the goods. In an open dryer or steam-heated floor this regulation of the state of the air used is not easy; the best that can be done is to keep the building closed and to use a little heat at first, the amount of ventilation and heat being gradually increased as the drying proceeds. Some clays are so tender that it is necessary to keep the bricks stacked close during the earlier stages of the drying and to re-arrange them when they are about half dry; this is too costly for use in a large works and a tunnel dryer is then preferable, provided that it has been properly designed, which is, unfortunately, seldom the case.

Burning the Bricks.—Although the drying of the bricks converts them into a mass of moderate hardness, they are not at all durable, and would be destroyed by any shower to which they were exposed. This is due to the fact that drying does not decompose the clay, but merely renders its plasticity latent; the decomposition must be effected by heating the clay in a kiln, this process being known as *burning* or *firing*.

Burning is effected by placing the bricks in a kiln in such a manner that the heat can distribute itself uniformly among them. Usually the bricks are "set" about ¾ in. apart in rows across the kiln, the direction of the rows being changed every few feet so as to cause a baffling action and better distribution of the heat. The kilns in which bricks are burned consist essentially of a brickwork chamber provided with a suitable number of fires arranged along its sides. The heat from these fires enters the kilns, being carried by the fire-gases, and as these pass through the kilns they come into direct contact with the bricks, heating the latter to the desired temperature, and then passing away to the kiln chimney or to another chamber to be similarly heated.

In the older types of kiln, the bricks are burned in a rectangular chamber with an open top, the fires being along the two longer sides, and the heated gases rising among the bricks and finally passing out through the top. Such an arrangement is known as an up-draught kiln. It is cheap to construct, but is irregular in action and wasteful in fuel. Bricks of much better quality and improved colour may be obtained by using a down-draught kiln; these are usually circular in shape, but are equally satisfactory if made rectangular. In a downdraught kiln the hot gases from the fire rise up channels or *bags* to the top of the kiln; they are thence deflected downwards among the goods, and finally pass out through the floor of the kiln to an underground flue leading to the chimney. Down-draught kilns are very uniform as regards heating, but they require from 8 to 15 cwts. of coal for a thousand bricks, whereas the same number of bricks can be equally well burned with 2½ to 4 cwts. of coal in a continuous kiln of suitable type.

In a single kiln, the gases which have been used for heating the goods pass directly to the chimney, but in a continuous kiln the corresponding portions (known as *chambers*) are placed side by side so as to form an endless series. The gases from one chamber pass into the next chamber and then to another, this being repeated until they become too cool to be of further use, and they are then allowed to pass up the chimney. In this way several chambers filled with bricks are heated by the gases from one set of fires, and the best possible use is, therefore, made of the fuel. At the same time, the heat in the finished goods is withdrawn by passing a gentle current of air over them, this air being used to burn the fuel required for heating the goods. When one chamber is finished, the firing is stopped, and the fires in another chamber are lighted, so that the action of the kiln is quite continuous, there being sufficient chambers in the kiln to enable one to be filled, another emptied, and the rest in various stages of burning and cooling. The great economy in fuel secured by the use of a continuous kiln is very marked, and it will usually be found that with a daily output of 16,000 bricks per day, the kiln will pay for itself in about two years. As there are many kinds of continuous kilns, it is important to use one which is properly designed for the particular class of goods to be burned and adapted to the peculiarities of the clay to be used; clays differ so greatly that where these precautions are not taken it may be impossible to secure good results in some works, though in others the same type of kiln works with complete satisfaction. The advantages of a continuous kiln cannot be realised unless there is a perfectly regular output of at least one chamber per day; with very low and irregular outputs it is better to use single kilns and to utilise the waste heat in another manner.

The changes which occur when a brick is burned are numerous and complex; indeed there is considerable difference of opinion as to what does actually occur. It is generally agreed that at a temperature of 500° C. (932° F.) the clay begins to decompose, losing water and changing its character completely. As the temperature rises the decomposition becomes more and more complete until a hard, stonelike mass is formed which has the well-known characteristics of *terra-cotta* or burned clay, such as porosity, hardness, etc. If the heating is continued at a still higher temperature, some of the constituents of the clay will begin to react with the clay and will form a fusible mass which, at a still higher temperature, will cause the whole brick to collapse, so that the heating must be stopped before distortion occurs or the brick will be spoiled. The matter which fuses runs in between the unfused particles, and as the bricks cool this fused mass very soon becomes solid and forms an intensely strong bond, producing bricks of great strength and resistance to crushing. The production of a sufficient amount of fused matter to form a good bond without permitting any distortion of the article is known as *vitrification;* the temperature at which it occurs depends on the size of the particles present in the "clay," the nature and amount of the impurities (particularly the metallic oxides) and the duration of the heating. The more impure the clay and the longer the heating, the greater will be the amount of vitrification at any given temperature.

If red bricks are desired, the kiln must be heated under conditions which provide for plenty of air gaining access to the kiln during the firing, but if it is desired to increase the strength of the brick without regard to the colour, and the clay contains a sufficient proportion of iron, it is better to restrict the air somewhat towards the end of the burning. The result of this is to rob some of the iron oxide of a part of its oxygen and to form another oxide which will readily attack the clay with the formation of a fusible compound. This latter substance forms the bond which increases the strength of the bricks, and, if the heating and restriction of air have been properly carried out, the bricks will be "blue" or almost black in colour. The enormously strong Staffordshire engineering bricks are made in this manner; if the same material is heated with a large excess of air, red bricks of much less strength are produced.

To burn bricks successfully requires great skill and much experience, and, as it is not the purpose of this volume to teach burning, it is sufficient to state here that the heating is continued until the desired colour is obtained in the bricks, or until a sufficient amount of vitrification has been produced. It is customary to fill the kiln almost to the top with bricks and to measure the "settlement" or shrinkage which occurs at intervals during the burning. As soon as a sufficient amount of shrinkage has occurred, the heating is stopped, and the kiln or chamber is allowed to cool slowly, the entrance of currents or draughts of air being prevented from spoiling the goods. Other methods of determining when the heating has been sufficient consist in the use of pyrometers or temperature-recorders, or in withdrawing small trial-pieces of a convenient shape from the kiln and examining these in various ways. The last-named method is specially used in the burning of glazed bricks, as, if these trial pieces are satisfactorily glazed, it is assumed that the bricks have been sufficiently fired.

Properties of Bricks.—The chief properties demanded in a brick are that it shall be strong enough for the work it is required to do, with an ample margin for unexpected strains; that it shall be accurate in size and shape, that its appearance shall be pleasing, and that it shall be capable of being laid readily in mortar so as to form a strong structure, sufficiently impervious to moisture, etc., and yet with good drying capacity.

To fulfil all these requirements in the highest degree is impossible in a single brick, as good drying requires porosity, whilst imperviousness needs a brick as devoid as possible of porosity; the purchaser must, therefore, decide the extent to which he is willing to forego something in one direction in order to obtain what he requires in another. Thus, a structure built of blue engineering bricks would be exceedingly strong, but, whilst it would be impervious to external moisture, it would probably prove damp internally, as there would not be the same facilities for the escape of internal moisture as in a similar structure built of porous bricks. It is a common mistake to suppose that when a house is damp the bricks are too porous; it not infrequently happens that they are not porous enough, and that the water inside the house cannot escape as it should do, or in other words the brickwork does not *breathe* properly.

The strength of different kinds of bricks varies greatly, and bricks from the same works differ in a remarkable manner in this respect. The weakest bricks in regular use have a crushing strength of about 80 tons per sq. ft.; the bricks made by mechanical methods, such as the wire-cut or the stiff-plastic process, have usually a crushing strength above 200 tons per sq. ft. and rising in some cases to 500 tons per sq. ft.; semi-dry process bricks should have a strength of at least 250 tons per sq. ft., whilst blue engineering bricks, made in Staffordshire, have a crushing strength of 400 to 780 tons per sq. ft. For safety, the following should be regarded as the minima for each class of bricks mentioned—

	Tons per sq. ft.
Engineering bricks	300
First class facing bricks	130
Common bricks for interiors . . .	90

The shape of a good brick should be such that its length is almost exactly twice its width, due allowance being made for the joints; the thickness is usually about half the width, but much thinner bricks are largely used. The standard size established by the Royal Institute of British Architects lies between the following limits: Length $8\frac{7}{8}$ and 9 in.; Breadth $4\frac{5}{16}$ and $4\frac{3}{8}$ in.; Thickness $2\frac{5}{8}$ and $2\frac{11}{16}$ in.

The porosity of a building brick should usually be such that, when the brick is immersed in water, it will absorb about one-sixth of its weight of water. Engineering bricks, on the contrary, should not absorb more than one-fiftieth of their weight of water, and the better qualities will not absorb any water at all. Bricks which are almost impervious are difficult to lay; as they tend to float on the mortar instead of being imbedded in it; the same objection is sometimes made to bricks made by the semi-dry process.

Glazed Bricks, in addition to the foregoing properties, require to be covered on the exposed face with a glaze which can withstand the action of the weather. The glazes ordinarily used for coarse pottery are rich in lead compounds, and are unsuitable for glazed bricks, as they crack and peel away when exposed to the weather. For glazed bricks, the only suitable glazes are leadless ones, in which the predominating constituent is felspar; these are fired at a temperature of at least 1,180° C. (2,156° F.), so that the bricks must be made of fireclay (Chap. XVII), or they would lose their shape at the same temperature as that at which the glaze melts.

CHAPTER XI

TILES

The manufacture of tiles includes the work of several branches of clayworking, as roofing tiles are made quite differently from floor tiles, and both are made differently from glazed tiles used for internal decoration.

Roofing Tiles are made in a manner similar to bricks, but, as they are only about ½ in. thick and are longer and wider than bricks, they require much more care in manufacture and burning. *Hand-made* roofing tiles are made in a wooden or iron mould in precisely the same manner as bricks (p. 71); wire-cut roofing tiles are made in the same manner as bricks, but the cutting wires must be arranged in a special manner so as to cut the tiles to the required shape. The holes in plain roofing tiles are made afterwards by means of a punch fastened to a convenient frame; the nibs or projecting portions of the tiles are made by the workman pressing the tile and so forming the nibs, or by leaving a space in the mould to form two small projections which the workman afterwards presses backwards with his thumbs. Some firms make plain cakes of plastic clay in a wire-cut machine and then mould these to shape by hand; they regard this as a quicker method than moulding wholly by hand.

What are known as *French roofing tiles* are made to interlock and so form a stronger and more weather-resisting roof. They are moulded in plaster-moulds in a power-driven press of special design. *Pan-tiles* are made flat, and are afterwards curved by stacking

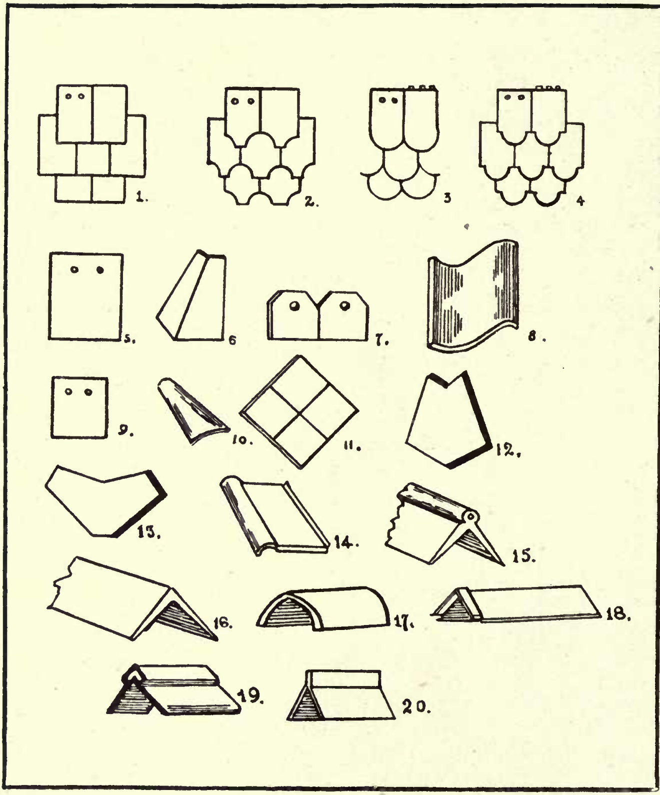


Fig. 20

ROOFING TILES OF VARIOUS PATTERNS

1. Plain tile; 2. fish-tail tile; 3. round-end tile; 4. club-end tile; 5. tile and half or gable tile; 6. octagon hip-tile; 7. ornamental or grooved ridge-tile. 8. pantile; 9. eave tile; 10. Madeira or Spanish tile; 11. diamond tile; 12. hip tile; 13. valley tile; 14. Roman tile; 15. rolled ridge-tile; 16. plain ridge-tile; 17. saddle-back tile; 18. capped ridge-tile; 19. expanding ridge-tile; 20. crested ridge-tile.

them on a stool whose top is curved to the shape of the finished tiles.

The clay used for roofing tiles is similar to that used for bricks, but is preferably of finer texture; it must be capable of being burned without any distortion, notwithstanding the disadvantages in this respect caused by the shape of the tiles. It is prepared in the same manner as clay for bricks (p. 69).

Roofing tiles require to be dried very slowly—many weeks being usually required—and are burned carefully and slowly in down-draught kilns. The burning must be arranged so that the tiles are sufficiently porous to afford the necessary ventilation, but yet sufficiently impervious to prevent rain passing through the tiles; this necessitates many pores of extremely small diameter, and consequently the use of a fine-grained paste, rich in clay, but containing sufficient non-plastic particles to dry without cracking unduly.

Apart from minor differences, the manufacture of bricks and roofing tiles is so similar that they may be considered as almost identical so far as the general reader is concerned; those who wish for further information are referred to the books mentioned at the end of this volume.

Floor Tiles are usually plainly square or rectangular in shape and, as their name implies, are chiefly used in the construction of floors, especially those which are required to stand hard wear without producing a dust and yet be resistant to water. They are preferably made of a clay which will vitrify sufficiently to form a tough and wear-resisting tile of considerable hardness and very low plasticity, some of the red and buff-burning clays in the Midlands being specially suitable for this purpose, though clays from other localities are extensively employed. Floor tiles are made by hand in wooden moulds and are afterwards re-pressed in the same manner as hand-made, re-pressed bricks (pp. 71 and 81), or they may be made by any of the other processes used in brickmaking (Chaps. VII—X). The burning must be continued until sufficient vitrification (p. 89) has occurred, as in the manufacture of engineering bricks, to which good floor tiles bear a close resemblance.

Owing to the limited number of clays which produce tiles of a pleasing red colour when vitrified, it is not unusual to find red floor tiles made of an ordinary brick clay; these are readily recognised by their porosity and should not be employed, as they are too soft to resist the wear and tear to which floor tiles are subjected in ordinary use.

Glazed Tiles are used extensively for internal decoration, hearths, etc. They are usually made of a buff-burning clay which is covered with a glaze. The clays used for this purpose are the buff-burning Midland clays and the fireclays, though others are sometimes employed. The clay or mixture of clay with non-plastic material is dried and ground to dust in a disintegrator or edge-runner mill and is carefully screened to remove all coarse particles. The dust is then placed in a screw-driven press (p. 83) and is compressed into tiles, one tile being made at a time; the various methods used for making bricks (Chaps. VII—X) may also be employed, but are seldom so satisfactory as the dry pressing of the dust. The dust-tiles are placed in fireclay boxes, termed *saggers*, in which they are burned in the kiln. The burned (biscuit) tiles are afterwards dipped in suitable slips (p. 64) so as to cover them with glaze, or first with a fine clay body and then with glaze. They are next dried and re-burned at a temperature which is suitable for the glaze. On allowing the kiln to cool and withdrawing them, the tiles are sorted, defective ones are removed, and the rest are ready for use.

The colours used for glazed tiles are made of various metallic oxides, those of iron, chromium, copper, cobalt and tin being among the most important. These oxides are prepared in various ways and are then added to the glaze slip before the latter is used. When a tile bears a definite pattern the latter must be painted or printed in glaze colours in a manner similar to Earthenware (Chap. XV).

Encaustic Tiles may be regarded as inlaid tiles ; they consist of a background into which is inserted one or more " clays " of different colours, the latter being arranged as a pattern. There are several methods of working, but the one generally preferred consists in having a mould fitted with a loose inset which forms the mould for the pattern. The "clays" used for this are then poured or pressed consecutively into the respective parts of the inset and are allowed to dry slightly. The inset is then removed and the remainder of the mould is filled up with the " clay " for the " background " of the design, this also being added in the form of a slip. In order to bind these various clays together the tile is " backed " with a commoner clay which fills the mould completely and gives the tile the necessary thickness and strength. After the tiles have been removed from the mould it is usually necessary to scrape the face of each one so as to make the pattern show clearly. The tiles are then dried carefully and are burned in a kiln until slightly vitrified ; this not only increases the strength of the tiles, but it greatly improves their durability, especially as encaustic tiles are largely used for floors.

CHAPTER XII

TERRA-COTTA

Terra-cotta is a term which, in the strictest sense, merely means baked or burned earth or goods of such material, but it has long been customary to apply it to articles which cannot conveniently be classed under any other popular term. Thus, blocks and architectural ornaments made of clay cannot conveniently be described as "pottery," and the term "terra-cotta" is advantageously applied to them. Hence in the modern use of the term, terra-cotta may be regarded as comprising blocks, carved and moulded work and various ornamental pieces used in architecture, with a possible extension to vases and other vessels made of unglazed clay.

The chief characteristic of true terra-cotta is that of a piece of burned clay with a thin but impervious "skin" which makes it resistant to the weather and to the abrasion experienced in ordinary use. Without this protective "skin," terra-cotta soon becomes disfigured by the weather and by use and is liable to deteriorate somewhat rapidly. For this reason all ornamentation should be completed before the material goes to the kiln, as any subsequent carving removes the protective "skin." In order to heighten this effect and to produce a white appearance, architects have recently used large quantities of what is termed "glazed terra-cotta"; this is ordinary terra-cotta glazed with a felspathic, leadless glaze, the coating being so thin or the glaze of such a nature as to prevent the formation of a highly glossy surface.

As many terra-cotta articles are very large it is necessary to use "clays" which do not shrink unduly nor crack readily in drying. The most satisfactory materials are natural mixtures of clay and very fine sand or highly siliceous clays. The former may be represented by some of the Midland red-burning clays, the latter by the fireclays. In all cases the material is made into a paste of moderate softness and plasticity by the methods described in Chapters VII and VIII.

Terra-cotta articles are either modelled, moulded or made on a potter's wheel, the last-named being described in Chapter XIII. *Modelling* consists in building up the article from a mass of clay paste, adding a piece here and removing one there until the desired shape is obtained; it differs from the work of the sculptor inasmuch as the latter must usually start with a large block and cut off this until the desired shape is left. In modelling terra-cotta it is often convenient to adopt the methods of the sculptor, using small wooden tools instead of a hammer and chisel, but the true artist will use his fingers extensively and will either add or remove material so as to obtain the effect he desires. For successful modelling, the paste must be moderately stiff and sufficiently plastic to adhere well when a fresh piece is added to the mass and to bend and twist readily when the modeller requires it to do so. Modelling is the preliminary stage in the making of almost any piece of terra-cotta or pottery, the duplicate pieces being obtained by the use of moulds made from the first or original model.

Moulding consists in preparing a mould (usually of plaster of Paris) of the article to be made and of filling the mould to the required extent with a suitable clay paste. This paste is pressed into position by the hands of the workman, aided by simple pads and other tools. In many cases, the construction of the mould is simplified by leaving a considerable amount of the work to the judgment and skill of the workman, so that in the moulding of the large, hollow terra-cotta blocks used in architecture, the face exposed in the building is usually produced by the mould, but the inner faces and the "ties" which increase the strength of the block are left for the man to "model" as best he can. The result is that moulding usually requires a large amount of skill. When the mould has been filled it is placed on one side so that the plaster may withdraw a portion of the water from the paste and so cause the article to shrink slightly; this shrinkage enables it to be removed readily from the mould. When this has been done, and the article is standing on a board, the workman examines it carefully, touching up any defects and smoothing out any undesirable roughness or small cracks. After this, the article is sent to the drying room, or is kept in a warm part of the making shop, and is allowed to dry very slowly. It is examined occasionally and may be turned on to its side or inverted so that it may dry uniformly. Parts which are liable to dry more rapidly than the rest must be kept moist by the application of damp cloths, as irregularity in drying is a frequent cause of cracked articles. When quite dry, the goods are sent to the kiln where they are burned in a similar manner to bricks (p. 86), in fact, the manufacture of terra-cotta and hand-made bricks greatly resemble each other, though the terra-cotta usually requires more care and attention on account of the larger sizes of the articles and the consequently far greater risk of damage by inattention.

Glazed Terra-cotta is made in a similar manner to that just described, but either before or after being burned it is coated, on the faces to be exposed, with a felspathic glaze slip applied by means of a brush. Some firms prefer to burn the ware before glazing it, but others apply the glaze to the unburned ware and so save the expense of one burning.

The most important characteristics required in terra-cotta articles are ample strength, combined with durability; the former is secured by the use of a suitable material—one which is neither too plastic nor too "lean," and the latter is obtained by the formation of the slightly vitrified "skin" previously mentioned. This "skin" forms automatically if a "terra-cotta clay" is used, and so causes no trouble to the manufacturer; it is apparently due to the finer particles which collect on the surface of the article, especially when the workman smooths it soon after it has been taken out of the mould. The colour of terra-cotta is usually a peculiar red, due to using clays containing iron oxide, but buff and even white terra-cotta is manufactured, suitable clays for these two varieties being abundant, though the product is seldom so durable as the red terra-cotta, because the buff and white kinds do not usually possess so marked a "skin."

Most architects and users of terra-cotta seldom realise the great care needed in its manufacture and the long period necessary for drying, burning and cooling the goods: three months may be required to produce a simple block, and some large and complex pieces require double or treble this time.

CHAPTER XIII

COARSE POTTERY AND SANITARY WARE

The term *Coarse Pottery* is applied to all vessels made of a natural clay to which no other material, with the exception of water, has been added. Such a definition excludes earthenware and porcelain, but includes all the pottery made of red-burning clay and the various appliances such as baths and other lavatory fittings known by the general term of *sanitary ware.* Coarse pottery chiefly comprises large pans, glazed only on the inside, flower-pots and the coarser domestic ware, all these having a naturally porous nature, and the similar ware made of impervious materials termed *stoneware,* described in the next chapter.

The clays chiefly used for coarse pottery have the general characteristics of terra-cotta and brick clays, the finer textured and red-burning clays being preferred. The articles are made of a plastic paste prepared by one of the methods described in Chapters VII and VIII, though in some cases the material has first to be cleaned, as described in Chapter VI.

The commonest method of making coarse pottery is on a potter's wheel, the operation being known as *throwing.* The potter sits just above and at one side of a flat disc which can be rotated at any desired speed, either by a youth who turns a large handle, or by some mechanical means, a rope being usually preferred to a belt for power-driven machines. The potter takes a lump of the paste in both hands and throws it violently on to the centre of the disc or *wheel* so as to make it adhere to the latter. Whilst the wheel is revolving slowly the potter presses his hands on the paste and according to the position of his fingers he makes it into any desired regular circular shape. If a vase is required, or any other hollow vessel, he presses one or both thumbs hard down on to the centre of the paste, so as to make it into a kind of tube and then proceeds with his shaping.

By courtesy of *Messrs. The Worcester Porcelain Co.*

FIG. 21

THROWER AT WORK

When the vessel is almost of the required shape, the potter may finish it with his fingers, but he usually prefers a small piece of wood, as he thereby obtains a smoother finish and a more accurate shape. The speed at which the wheel revolves must be adjusted to suit the shape and size of the article to be made ; in the more primitive hand-driven wheels, the potter calls out instructions to the boy assisting him, but in using a power-driven wheel, he regulates the speed by means of a foot-brake. When the article is completed, the potter stops the wheel and cuts off the article by means of a tightly-stretched wire. The article is then lifted on to a board, and then taken away to be dried, usually on the shelves of a warm room.

Some pieces of coarse pottery are made by moulding (p. 99); this is more expensive than throwing on a potter's wheel when the articles are simple in shape, but the products are more exact in size.

The body of coarse pottery ware being porous it is necessary to glaze it before the articles can be used to hold water or other liquid. The glaze is applied in the form of a slip consisting of galena, ball clay, flint and water, which is poured into the vessel to be glazed; the latter is moved so that the whole interior is covered and the surplus glaze is poured out. The vessel is then set aside to dry and is afterwards burned in a potter's oven (p. 122). When the outside of an article is to be glazed, the article is dipped into the glaze slip. The glaze is usually dark brown in colour when the goods come from the kiln; if a black glaze is required a little manganese ore is added to the slip before use. If the inside of the vessel is to be white or cream coloured, the vessel is first rinsed out with a slip made of ball clay, flint and water, and when this has dried, it is treated with glaze, as before. The intermediate coating of slip will produce the light coloured interior.

Sanitary Ware is largely made of fireclay or of a mixture of fireclay and a white-burning pottery clay in convenient proportions. The ware is usually moulded (p. 99) from a plastic paste made by grinding the fireclay and then mixing it with water as described in Chapters VII and VIII. Quite recently, sanitary ware has been made by casting like Earthenware (Chap. XV). The essential feature of most sanitary ware is that it shall be strong, that the glaze on it shall be quite impervious to any liquids with which it may come in contact, and that it shall be entirely free from all tendency to crack or craze. These conditions can only be obtained by the use of felspathic, leadless glazes, burned at a high temperature and similar in many respects to those used for glazed bricks (p. 92). The glaze is usually applied in the form of slip by means of a brush either to the burned or unburned goods, and after they are completely dry they are fired in muffle kilns in which they are protected from the direct action of the fire and flame. The size of the goods and the high temperature at which they are burned make the manufacture of sanitary ware of first class quality peculiarly difficult. This is specially the case with baths and large tanks, as these are made by gradually building up the article without much aid from moulds; the manufacture of these articles is, in fact, a form of modelling (p. 99) on a large scale. The manufacture of sanitary ware is essentially one in which the principles involved are comparatively simple, but the materials are peculiarly difficult to manage, and unless great care and skill are employed, it will be impossible to obtain good results. Like architectural terra-cotta, sanitary ware requires a long time to dry, burn and cool, so that, if the goods have to be made to order, ample time must be allowed for their manufacture.

CHAPTER XIV

STONEWARE AND DRAIN-PIPES

THE term *stoneware* is used to include all ware with an impervious, vitrified body, with the exception of porcelain. It is chiefly applied to goods intended to contain liquids (including corrosive chemicals) or through which such liquids may be required to flow. The texture and surface of stoneware also lend themselves to decorative effects, so that panels and large tiles are made of this material.

The clays or mixtures used for stoneware must be such that they will vitrify and become impervious without suffering any appreciable amount of distortion. Some of the ball clays are particularly suitable for this purpose, and are commonly known as "stoneware clays." As other plastic clays are unable to vitrify sufficiently without loss of shape it is customary to add some flux such as Cornish stone or felspar which will combine with some of the clay and form a vitrified mass. By the use of a suitable flux a fireclay may form an excellent stoneware clay, in fact some fireclays contain sufficient natural fluxes to make good stoneware of a coarse variety without any addition being necessary.

Stoneware articles are made in a variety of ways according to their shape; many of them are made by the methods described for Coarse Pottery (Chap. XIII) or for Earthenware (Chap. XV), whilst others are moulded as described in Chapter XII. The mode of manufacture does not differ materially from that of other clayware, as the properties of stoneware depend on the raw material and on the manner of burning more than on anything else.

Drain-Pipes are commonly included in stoneware, though some of them are made of a porous body covered both internally and externally with a glaze. The best drain-pipes are, however, made of stoneware. Such pipes are made by machines similar in principle to the wire-cut bricks machines described in Chapter X, but arranged in such a manner that the pipe is delivered in a vertical position, whereas bricks are made from a horizontal column. The pipes used by farmers for land drainage are, however, made horizontally.

The clays used for glazed drain pipes are usually the less refractory fireclays; unglazed drain pipes being made of the same clay as is used for bricks. The raw material is made into a paste as described in Chapters VII and VIII. This paste is then placed in a pipe machine which may consist of a cylinder fitted with a piston driven by a steam-chest, the cylinder having an opening at one end through which the paste is expressed by the piston. In the centre of this opening is a metallic disc or *core* with a space all round it, and it is through this annular space that the paste is expressed in the form of a pipe. The cylinder is emptied, the piston drawn back to its full height by applying steam to the lower part of the chest and the cylinder is then filled with clay paste and closed. The piston is then driven forward by steam pressure and forces the clay out of the cylinder. Operated in this manner it would produce pipes without any socket, the latter being formed by a kind of "collar" which is temporarily affixed to the opening in the cylinder. This collar allows the clay to form a short piece of pipe of enlarged section, and as soon as this is completed the collar is loosened from the machine and travels downwards with the pipe. When the latter has attained a sufficient length it is cut with a taut wire and is carried away to be dried. The collar is then re-attached to the machine. Various modifications of this arrangement exist; thus the collar may be made in two pieces, hinged so as to open sideways and allow the pipe to pass between them after the socket has been completed, or the machine itself may be a simple vertical pugmill, the outlet of which is fitted with a suitable mouthpiece.

The pipes are sometimes trimmed immediately after they have come from the machine, but unless they are made very stiff it is better to allow them to dry slightly so as to make them firmer and less liable to distortion during the trimming or *fettling* process. This consists in mounting the pipe on a vertical or horizontal cylinder and turning it slowly by mechanical power whilst a workman applies a small sponge or rubber to the surface so as to smooth the latter and remove any defects. Any cracks are removed at the same time by means of a knife, and the grooves in the socket and on the spigot are made at the same time. The pipe is then removed and placed on a small stand or directly on the floor of the drying shed, where it is allowed to dry slowly, being turned over at least once during the drying in order that there may be no distortion.

The dry pipes used for agriculture are burned in brick kilns, being placed vertically on top of the bricks. They must not be heated too strongly, as they are required to be as porous as possible. The pipes used for sewage and general sanitary purposes are salt-glazed and burned simultaneously in the following manner—

The pipes are placed vertically in a round down-draught kiln, the smaller pipes being placed inside the larger ones and piled on top of one another until the kiln is filled. It is necessary that all the pipes shall be placed vertically, as otherwise they would not be glazed all over, and the draught of the kiln would also be affected. The pipes are burned in a manner similar to bricks, but when a trial (a piece of broken pipe placed in a convenient part of the kiln) is withdrawn, and shows that vitrification has commenced, it is time to commence the "salting." This consists in making up the fires with plenty of coal so that they glow brightly and will last some time without attention, and then throwing a shovelful of common salt on to the back of the fire and filling up the front with coal. If the operation has been properly managed the salt will begin to jump about inside the kiln, and will eventually come in contact with the pipes to which it will adhere. As soon as this occurs a chemical combination between the salt and the clay takes place and a glaze is formed on the pipes. The glaze melts and flows uniformly over the surface of the pipes producing a glossy brown glass of characteristic appearance. It is usually necessary to continue the heating, after the first dose of salt has been added, until the temperature has regained what it lost by the formation of a glaze. The kiln is then treated with a second dose of salt, and further doses may be given after subsequent heatings, if they are found to be necessary. This is ascertained by looking in the kiln through "spy-holes" provided for the purpose and by withdrawing broken pieces of pipe specially inserted as trials and examining the glaze on these. When a satisfactory glaze has been obtained the kiln is allowed to cool slowly with little or no admission of air.

Salt glazing is less easy than it appears to be at first sight. The fires require very careful regulation in order to produce a satisfactory result, as the admission of too much or too little air will produce a great difference in the colour of the pipes, insufficient air producing pipes which are too dark to be pleasant, whilst with an excess of air it is sometimes very difficult to get a glossy surface on the goods.

It has been explained in Chapter I that clays are essentially acid in character, and like other acids they can decompose certain salts, turning out the acid element in the salt and replacing it by the acid in the clay. In salt-glazing what occurs is the replacement of the chlorine in the salt by the clay-acid with the formation of a readily fusible alumino-silicate; the chlorine is set free in the form of hydrochloric acid gas which escapes up the chimney. The precise composition of the alumino-silicate formed depends on the clay used; with silica alone it is almost impossible to get a good salt-glaze, and some clays contain alumino-silicic acids which will not prove satisfactory at the temperatures at which it is most convenient to work. The most satisfactory clays are the lower grade fireclays and certain ball or stoneware clays, all of which are relatively rich in silica.

The advantage of salt-glazed ware over that glazed by the application of a fusible dip is the simplicity of the process of glazing and the great durability of the glaze. Although produced at a convenient temperature (1,100° C. or 2,000° F.) it does not crack like lead glazes and it is particularly resistant to acids. Its drawback is its somewhat uneven surface and the extent to which it is coloured brown by impurities in the clay; these defects may be overcome by dipping the goods to be glazed in a suitable body-slip of purer clay, but this is unnecessary for drain-pipes.

CHAPTER XV

FINE EARTHENWARE

THE term *earthenware* is usually employed to include all the wares (other than porcelain) which are used for domestic purposes, particularly for table ware and cooking. The ware used for heating food is sometimes more correctly described as stoneware, thus pie-dishes are usually earthenware, but stew-pots are stoneware (Chap. XIV). In a still broader sense the term is used to include all ware made of clay and glazed, but such a definition is too inclusive for general use and must be sub-divided into Coarse and Fine Earthenware ; the former is described in Chapter XIII.

Fine or Domestic earthenware consists of a porous body made of a white-burning clay which, in its turn, is covered with a glaze. Fine earthenware is always burned twice ; once in order to harden the body of the ware, and the second time after the application of the glaze. The second heating is at a lower temperature than the first.

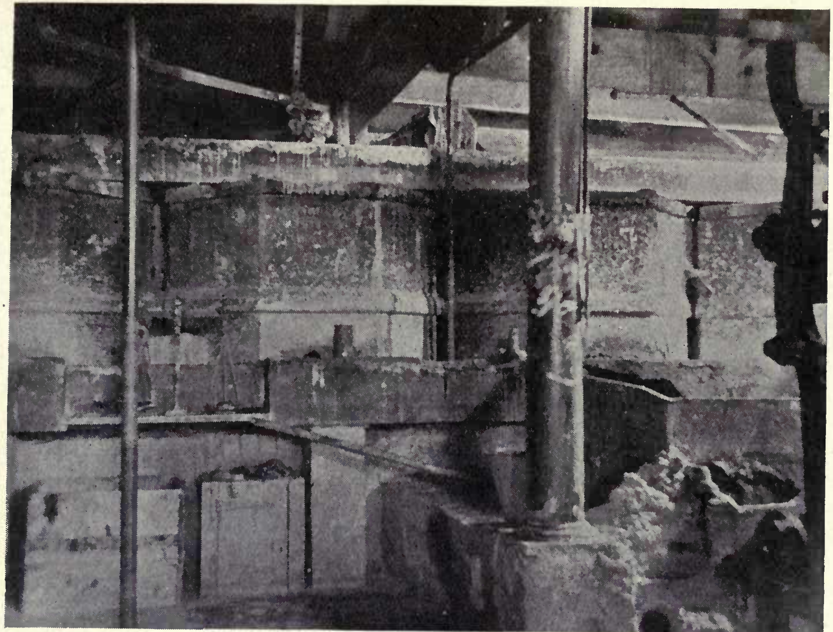
Materials.—Fine earthenware is made of a mixture of three classes of substance (*a*) clay (*b*) glass-forming materials such as Cornish stone, felspar, and (*c*) indifferent substances such as flint. China clay and ball clay are the chief clays used, a somewhat larger proportion of the latter than of the former being employed. The china clay is necessary, as the ball clay alone would shrink too much and would not burn sufficiently white. The Cornish stone vitrifies on burning and forms a bond which unites the particles of clay and flint into a sound, strong mass. The flint is chiefly used to reduce the contracting of the material to within convenient limits, but it also fulfils a useful purpose in adding free silica to the mixture.

Preparation.—The materials are each supplied in a form in which they can readily be reduced to a slip or cream when mixed with water; in the case of the flint and Cornish stone it is necessary to use materials which have been very finely ground. The raw materials are placed in a blunger (Fig. 22) with a suitable quantity of water, and after the two have been thoroughly incorporated in the blunger the slip is ready to run into the mixing ark. To ensure the correct proportion of material being used in the earthenware, the slip is allowed to rest a moment and the net weight of exactly one pint of it is carefully ascertained by weighing. The following densities are usually regarded as the most suitable; if thinner slips are used the solid matter tends to separate unduly—

Ball clay	24 oz. per pint.
China clay	26 oz. per pint.
Flint[1]	32 oz. per pint.
Cornish stone[1]	32 oz. per pint.

To produce a suitable earthenware body, these slips must be mixed in suitable proportions, the measurement of which is effected in a very simple but peculiar manner. As the proportions are measured by volumes it is customary to run the slips, one at a time, into the mixing ark (p. 114) and to insert a plain wooden staff, marked clearly in inches, in the ark. As the sides of the ark are vertical, the proportionate volumes can be measured directly by the depth of fluid in the ark; the increase in depth caused by the admission of each slip being expressed in inches on the measuring staff which are wetted by the fluid. A little thought

[1] Flint and Cornish stone are sold in the Potteries in the form of slips of the density mentioned, and so do not need blunging before use.



By courtesy of *Archdeacon Graham.*

FIG. 22
BLUNGERS

will convince the reader that this gives the same results as if the slips were measured in gallons or cubic feet, and it is much simpler and less liable to error.

The following proportions are frequently used, they are stated, as described above, in "wet inches"—

BODY FORMULAE FOR EARTHENWARE
(in Wet Inches)

Quality of earthenware	*Good*	*Medium*	*Common*
Ball clay slip (24 oz. per pint)	10	12	15
China clay slip (26 oz. per pint)	8	8	8
Flint slip (32 oz. per pint)	5	5	4
Cornish stone slip (32 oz. per pt.)	2½	2½	2

These proportions are varied slightly according to the composition and varying characteristics of the materials.

The desired proportions having been decided, the blunger containing the ball clay slip is fitted with a fine sieve or *lawn* at its outlet and the slip is run into another blunger until the latter is filled to (say) 10 in. from the bottom. The supply of ball clay is then shut off and the china clay is run through another lawn into the blunger (the latter being known as a *mixing ark*) until the fluid in it has risen a further (say) 8 in. The china clay slip is shut off and the proper proportions of flint and stone are successively added in a similar manner. Finally (except for the common ware) a little cobalt oxide, ground exceedingly fine and made into a slip of similar consistency to the others, is added in such a proportion as to neutralise the yellowish shade of the burned ware and to improve its whiteness. The purpose of this *stain* is precisely the same as the use of blue in laundry work to whiten clothes which, without it, would have an unpleasant yellow tinge. The blue colour produced by the cobalt neutralises the yellow colour of the burned clay and so produces whiter ware. Too much stain must be avoided or the ware will be blue.

The various slips are mixed thoroughly in the ark, and when this stage is complete the mixed slip is pumped on to a series of lawns or sieves of silk or phosphor-bronze wire, through which the fine particles pass, whilst the coarser ones are held back. The screened slip is then passed down a trough containing powerful electro-magnets which retain any particles of metallic iron which may have entered the slip during the grinding or blunging of the materials. This iron, if left in the slip, would produce reddish or yellowish spots in the ware and would disfigure it. After this, the slip is passed into a *finishing ark*, which is similar to the mixing ark, and in this slip is once more mixed thoroughly so as to secure uniformity of composition. The mixed slip is then treated so as to remove the greater part of the water present and to convert it into a paste of convenient consistency.

In olden times the slip was run into a large shallow tank, the bottom of which was heated by flues beneath it. On this dryer, the water gradually evaporated leaving an irregular pasty mass which required thorough mixing before it could be used. In order to produce the paste at a greater rate and at a less expense, it is now customary to employ filter-presses (Fig. 8) instead of a dryer. When all the surplus water has been removed the cakes of paste are taken out of the press, rolled up and carried away, the cloths being replaced by clean ones as often as necessary. These press-cakes are, in many respects, quite as good as the paste formed by the hot floor (or *slip-kiln*), but the latter produces a slightly more plastic and stronger material which is preferable where cost is a secondary consideration.

The paste from the presses or slip-kiln must be pugged (p. 53) in order to make it uniformly consistent, as otherwise it would shrink irregularly, and would cause distortion in the articles made from it. The pugged paste is then ready for use, though its quality is improved if it is stored for some time in a cool place and then pugged a second time.

Making Earthenware Goods.—Articles made of fine earthenware are made in several ways, including throwing and casting, but they are chiefly formed in plaster moulds from a plastic paste prepared as described above.

Throwing has been described on p. 102. It is seldom that this method produces articles sufficiently accurate in shape for fine earthenware; it is therefore customary to allow the articles to become almost dry and then to turn them accurately to shape in a lathe (Fig. 23), just as though they were made of wood or metal.

Casting is chiefly used for very thin ware. The articles are made by pouring slip from the finishing ark into the moulds, allowing it to remain a short time and then pouring out the surplus fluid. On examining the mould it will be found that the plaster has absorbed a large proportion of the water in the slip and has left a coating on the inside of the mould. This "coating" will shrink slightly as the mould dries, and can be removed later in the form of the article it is desired to produce.

Casting enables vessels of very complex shapes and with very thin walls to be made readily and at a lower cost than by other methods; it has its own special difficulties which limit its application and so cause a very large number of vessels to be made by other methods. Casting is, however, largely employed for cups and other hollow ware.

Pressing or Moulding is effected in plaster moulds, the paste being treated in a manner similar to that described on p. 99. As earthenware paste is finer in texture, it is easier to get fine detail in small articles

By courtesy of Messrs. W. T. Copeland & Sons.

FIG. 23

TURNING POTTERY

than with the paste used for terra-cotta. Earthenware manufacturers never use the term "moulding," but invariably employ the term "pressing" for this work.

Much domestic earthenware is made with the aid of a machine which carries the mould and rotates it whilst the workman holds a specially shaped arm (termed a *profile*) on to the paste and by this means forces the paste to take the desired shape. By the use of a profile the mould can be made to produce the outside shape or the lower face of an article, whilst the profile forms the inside or upper face. Thus a plate-mould placed on such a machine has a slab of paste laid on it and the profile is pressed on to the clay. As the mould revolves, the clay-paste is spread out between the mould and the profile, the former making one face and the latter the other one on the plate. As plates and saucers are always made "upside down" the profile forms the "bottom" of the plate. The machines used for this work are known as *jiggers* and *jolleys;* both types work on the same principle, the names merely serving to distinguish the machine used for flat ware from that used for deep hollow ware. Quite recently there have been attempts at producing pottery in steel moulds in a manner similar to that used for pressing bricks (p. 78), but so arranged that both the mould and the plunger are revolved when in use. This arrangement has proved highly satisfactory for ware not less than $\frac{1}{4}$ in. thick and it effects an important economy by saving the expense inevitable in the renewal of moulds when these are made of plaster. The use of these steel moulds, with their corresponding greater pressure also does away with the need for a *batting machine* to beat the paste into a suitable shape before it can be put on the plaster mould.

Ware which is not circular in plan cannot be made on machines in the manner just described; it must be moulded by hand in plaster moulds as described on pp. 99 and 100. Some articles are so small that great skill is needed to mould them properly, the joints being fine, strong and invisible and yet avoiding the use of an unnecessary amount of material. For this reason, casting is often preferred for the more complex articles, as by its use joints are avoided.

By courtesy of *Archdeacon Graham.*

FIG. 24

MAKING CUPS ON JIGGER

Cups, jugs and other articles with one or more handles are made without any handle by any convenient method, the handle being moulded separately and attached afterwards by moistening both the article and the handle and pressing them together. The feet of tureens and other articles are also made separately and attached in a similar manner.

Dust Pressing (p. 96) is used for some earthenware articles.

Drying.—Fine Earthenware is usually so thin that it can be dried in warm chambers or *stoves* (Fig. 25), the goods being placed on open shelves and the drying being effected at a fairly rapid rate. The larger articles and those with thicker walls must be dried more slowly and with more precautions to prevent cracking and distortion. For small articles made in fine earthenware, the shelves on which the ware is dried are fitted in a revolving frame which is rotated little by little as the maker fills up one section; this enables the men to work in a cooler room than that in which the ware is dried, and it also reduces the amount of space occupied and the distance the ware has to be taken to be dried.

Decorating the Ware.—To a large extent the production of designs in relief, or in other ways in which the ornamentation is due to the shape of the surface of the clay, is effected automatically in the moulding, but where this is impracticable the ware may be ornamented by modelling with the hands or with small tools, by attaching pieces which have been moulded separately—as the white figures in Wedgwood's jasper ware—by cutting away certain parts and (in some cases) by refilling the vacant places with coloured clays. Ware may also be decorated by a process of engraving or engine-turning, by dipping the ware into a slip which will burn to a different colour and afterwards removing part of the added slip so as to form a two-colour design, and finally, by painting designs on the ware by means of slips which burn to various

By courtesy of *Messrs. W. T. Copeland & Sons.*

FIG. 25

GREENHOUSE OR DRYING ROOM

colours. The possibilities in these directions are very great and enable exceedingly beautiful effects to be produced in a comparatively simple manner. The decoration of the ware must usually be made after it has dried fairly hard but before it is burned, though great latitude is permissible in this respect, some forms of decoration being more readily applied to the burned ware.

Burning.—Fine earthenware is burned in a potter's oven, the ware being packed in *saggers* or fireclay boxes which are piled one on another until the oven is completely filled. These saggers not only form a convenient means of supporting the ware but they keep it protected from the direct action of the smoke and dust inside the oven. Each pile of saggers is termed a *bung*, and the various bungs are arranged in *rings* concentric with the oven.

Potter's ovens are of various types, but the ones generally used are circular ones of the up-draught type, the heat being derived from the fires placed round the circumference of the oven and delivering the hot gases and flames in two series—one set travelling upwards to the top of the oven whilst the others go under the floor of the oven and pass up through an opening in its centre. This arrangement secures the centre of the oven being adequately heated as well as the parts nearer the circumference. The oven is usually surmounted by a conical chimney which may rest upon the oven or may surround it completely; in the latter case a *hovel oven* is formed with the advantage that the fires and workmen are better protected from the weather than in an ordinary oven in the open air.

Round down-draught ovens (p. 87) are also used for earthenware and are specially suited to works manufacturing a limited range of colours, as the temperature in these ovens is very uniform.

What appears likely to be the "oven of the future" for pottery is known as the *tunnel oven*. This is in the form of a long tunnel, the ware being placed on wagons at one end and travelling through the tunnel, being

By courtesy of *Archdeacon Graham.*

FIG. 26

MAKING BASINS

gradually heated, burned and then cooled whilst on its journey and emerging at the other end in a cool state. The fires are confined to the central part of the kiln, and the fire-gases are so arranged that they cannot come into contact with the goods. There are various arrangements in use, but all work on the same general principle and depend on the regular supply of goods which are passed through the kiln at a slow but steady rate.

The temperature reached inside the kiln or oven must not, as a rule, exceed 1,250° C. (2,282° F.) or the ware would be over-fired and distorted. The temperature is not measured directly, however, but the effect of the heat on the ware is determined by examining trial pieces withdrawn from the oven or kiln. The contraction of these pieces is measured accurately and gives a very fair idea of the progress of the burning. It is also necessary to pay careful attention to the appearance of the interior of the oven during the burning, as the most skilled burners rely quite as much on this as on the trials.

When the trials show that the ware has been sufficiently baked, the heating is stopped, the openings for fuel and air are closed and the oven is allowed to cool slowly. When quite cool, the doorway is opened by removing the brickwork of which it is composed and the oven is emptied by the men known as *drawers*. These men, like the *placers* engaged in filling the ovens, must be careful and conscientious workers or the breakage of the ware will be very heavy. The ware drawn from the oven is placed on benches or on a floor where it can be sorted, the useless articles being thrown away, and those whose defects can be remedied being treated in an appropriate manner. At this stage the ware is known as *biscuit*, a singularly inappropriate term, as its real significance is "twice cooked." For some purposes, biscuit ware of fine earthenware is useful, but it should usually be regarded as an intermediate stage, as, for most purposes, it requires to be glazed before use.

Under-glaze Decoration.—When a design is painted on the biscuit ware it is known as *under-glaze decoration*, as the ware is afterwards glazed and the decoration is thereby fully protected from abrasion. The colours used for this purpose are the oxides of various metals prepared so as to produce tints of the desired shade when burned. Thus, chromium oxide is the basis of many greens, cobalt of most of the blues, and so on (see p. 97). The colours appear quite different in the raw state to that after they are fired, so that the artist must have considerable experience of the particular materials used and the changes effected in the kiln before accurate shading can be accomplished with certainty.

The colours are mixed with a residual oil derived from turpentine—termed *fat oil*—and the resultant paste is applied with a brush or small sponge or by spraying a slip on to the ware. Various mechanical devices are used to facilitate the decoration of the ware, such as standing the article on a revolving table when painting bands or horizontal lines on it. Designs are also applied by a special form of printing, the colour being applied to an engraved plate, printed from this on to a sheet of prepared paper and then transferred from the latter to the ware. The design may be wholly in one colour and printed throughout, or the outline may be printed and transferred to the ware, the design being afterwards filled in with colour applied by hand.

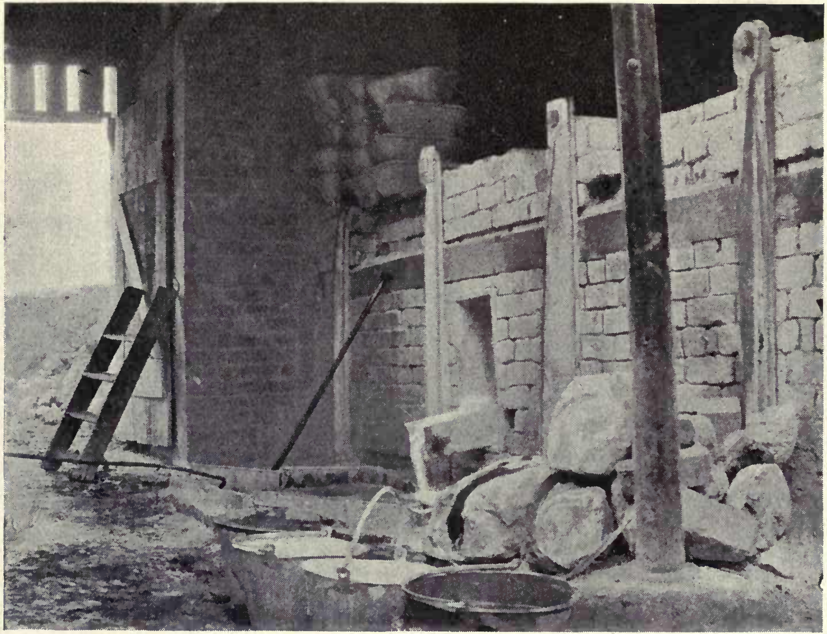
The oil, which has been mixed with the colour in order to facilitate its application to the ware, must be burned away before the glaze is applied, as glaze will not adhere to an oiled surface. The decorated ware is, therefore, heated in a muffle kiln at a dull red heat until all the volatile matter has been removed. The ware must then be handled with great care, as the decoration is easily damaged at this stage of manufacture.

Under-glaze decoration affords the maximum of durability, and it also gives the ware a greater depth of tone than can otherwise be produced. Unfortunately, the heat required to fuse the glaze limits the range of tints which can be used, the more delicate colours having to be applied to the glazed ware (see p. 130).

Glazing.—The biscuit ware, either plain or decorated, must next be glazed. This is effected by dipping it in a slip composed of some or all of the following materials mixed in suitable proportions : Borax, boracic acid, Cornish stone, felspar, whiting, china clay, flint, and white or red lead. It is usual to melt the bulk of the material other than the lead and to grind the frit so produced to a fine powder which is afterwards mixed with the lead and also with some Cornish stone, and possibly with some flint. Various other materials such as soda may be used, and sometimes materials bearing other names, but identical with one of the foregoing, are employed ; thus *tincal* is a crude form of borax. Each manufacturer of earthenware has one or more glaze recipes which he varies according to the requirements of his bodies, for the glaze and body must have the same shrinkage when burned in the glost kiln or the ware will craze. The following recipe may be taken as typical, but it will require adaptation to suit any given works—

Frit or fuse together

Borax . . .	30 lbs.
Cornish stone . .	30 lbs.
Whiting . . .	20 lbs.
Flint	15 lbs.
China clay . . .	5 lbs.



By courtesy of *Archdeacon Graham.*

FIG. 27
KILN FOR MELTING FRIT

The frit is ground to a fine powder and is then mixed with the following—

Frit	100 lbs.
Cornish stone	30 lbs.
White lead	50 lbs.

The glaze materials must be ground sufficiently fine before they are made into a slip or the resulting glaze will not fuse properly and will be very irregular in composition. Great care is essential in the preparation of glazes, and unless this work is done by a careful man it may lead to endless trouble.

The glaze is usually applied to the ware by dipping the latter into the slip, the ware being held in such a manner that all parts to be glazed are covered by the slip. The density of the slip and the porosity of the ware will largely determine the thickness of the coating, which must be regulated to suit the nature of the ware. Any uncovered parts may be covered with a little slip applied by the fingers or a brush, but such patch-work must be avoided as far as possible. Considerable experience is required to dip ware successfully and to avoid an excess of glaze in any part of the ware. As soon as the ware has dried it is examined, and any superfluous glaze is trimmed off, after which it is ready for the glost oven where the glaze is fused and made glossy.

Glost Firing.—The ware is placed in the glost oven in saggers (p. 122), but it is necessary that each article should be supported in such a manner that the glaze on it is not damaged during the burning. For this reason, care must be taken that no glazed surfaces touch each other and that nothing comes in contact with any part of the ware which will touch the glaze and spoil it. It is impossible with some kinds of ware to avoid a slight spoiling of the glaze, but the damage is reduced to a minimum by the use of pointed supports termed *spurs* or of other supports with sharp edges, which are known by a variety of terms, such as *dumps*, *stilts*, *thimbles*, *saddles*, etc. By the use of these appliances the articles can be placed very close together, yet without touching, and the defects caused by the supports in contact with the glaze are so small that they can scarcely be observed unless one is looking for them. They may be seen at the bottom (inside) many basins, and near the edge of the underside of plates and saucers, about three small points in each case showing where the supports have been placed. Where the price paid for the ware is sufficiently high it may usually be made without appreciable defects caused by supports, but the avoidance of their use with ordinary ware would enable so few pieces to be placed in the kiln that it would make the cost of burning the ware prohibitive.

Great care is necessary to place the ware in those parts of the oven where they will be suitably heated. The white ware should be placed in the outer ring (p. 122) together with some of the less sensitive colours such as black and brown ; the bulk of the printed ware should be placed in the second ring and intermediate between the centre of the oven and the circumference. Ware decorated with pink, purple and mauve colours must be fired in the cooler parts of the oven as they are very sensitive to overheating ; blue, green and yellow ware may be placed rather higher, as they are less sensitive. This variation in the heating power of various parts of the oven is often regarded as a defect by patentees, but in reality it is essential to the manufacturer of earthenware, as he is thus able to burn various colours in the same oven, which he could not do if the oven were heated uniformly throughout. This is one reason why the use of down-draught ovens and tunnel-kilns has made such little progress in earthenware manufacture.

The temperature in the cooler parts of an earthenware glost oven is usually about 1,040 to 1,100° C. (1,904° to 2,012° F.), but the heating is regulated to suit the glaze employed. The oven must be heated moderately rapidly, yet not so quickly as to spoil the ware; too slow a heating tends to dull the glaze. The cooling should be rapid at first, but slow as soon as the glaze has solidified, so as to obtain a high gloss with very little risk of cracked ware.

The glazed ware, after removal from the cool oven, is carefully sorted according to its quality and whether it is finished or requires to be further decorated. Any roughness on the ware may be removed by grinding or polishing, and some of the defects may be removed by over-glaze decoration, but when all possible care is taken a notable proportion of the ware will be found to be damaged and practically useless.

Over-glaze Decoration.—Many colours, otherwise inapplicable, can be used on pottery if they are applied to the glazed ware. The reason is simple, namely the temperature at which over-glaze colours can be fired may be regulated to suit the colours, whereas in under-glaze work the glaze has to be considered. As over-glaze decoration is usually burned at a very low temperature (usually below 900° C. or 1,650° F.) it may be rapidly passed through the kiln and this method of decoration therefore affords a simple and relatively inexpensive method of producing large quantities of decorated work in a short time. The great drawback of over-glaze decoration is the ease with which it is removed by the abrasion to which it is subjected when the ware is in use; this is quite unavoidable and largely limits the use of this method to cheap ware and to that used solely for ornamental purposes. Gilded ware is almost always made by applying the gilt over-glaze and the rapidity with which this part of the decoration is "washed off" cups and saucers is well known to all housekeepers.

Over-glaze colours are, like those used in other branches of pottery, made primarily of metallic oxides (p. 97) which are mixed with a *flux* such as

Red Lead	3 lbs.
Borax	2 lbs.
Flint	1 lb.

The colour and flux are fritted together (p. 126), and the fused mass is afterwards ground to a fine powder. Sometimes the flux is fritted alone and is only mixed with the colour during the grinding process. The proportion of colour and flux must be adjusted to suit the temperature at which the enamel kiln is worked and also the amount of gloss required in the ware; the greater the gloss required the larger must be the proportion of flux.

Over-glaze colours are applied either by printing or painting (p. 125), the colours being mixed with fat oil, or printer's oil, as the case may be, but sometimes a process known as *dusting* or *ground laying* is used. This consists in covering the part of the article to be decorated with a specially prepared oil and applying powdered colour with cotton wool or mixing it with the oil and applying it through a sprayer.

Metallic Effects, including *gilding,* are applied by using the metal or a suitable substitute ground up with oil or some suitable adhesive and painting the mixture on to the ware. The metallic parts will appear dull when they come from the kiln, but may be burnished by rubbing them with a suitable tool. Some preparations of gold are now largely used which give a bright

By courtesy of *Messrs. W. T. Copeland & Sons.*

FIG. 28

ENAMEL KILN

gilt in the kiln and so avoid the necessity of burnishing; incidentally they reduce the cost of gilding by enabling a much thinner coating of gold to be used. *Lustrous effects* are obtained in a similar manner, but some of them are due to accidental reduction of the oxides by the oven gases or by the use of special reducing agents.

Placing and Firing.—The ware with over-glaze decoration is placed in iron baskets or on shelves in the enamel kiln (Fig. 28); when necessary, it is supported in a similar manner to under-glaze ware, though much of it is placed as shown in the illustration.

The firing of a kiln containing over-glazed ware is usually checked by observing the appearance of trials printed with rose colour (purple of Cassius) the tint of which is changed with increasing temperature. This somewhat crude method is still preferred by potters to a direct measurement of the temperature by pyrometers or other instruments. The use of gas for firing these kilns is much better than that of a coal fire, and equally simple to manipulate. If the gas is made close to the kiln it is much cheaper than coal gas, and does not involve any more trouble than ordinary coal firing, whilst it enables a far more uniform temperature to be maintained. The use of a small tunnel-kiln for this purpose has many advantages over the older type of enamel kiln and is much cheaper to use (p. 122).

The ware drawn from the enamel kiln must again be examined and sorted, after which it is usually ready for sale. If highly decorated with many colours, however, it may be necessary to paint each separately and to pass the article through the kiln after each colour has been applied. Thus, ware with a design in six colours may have to pass six times through the kiln before it is completed.

CHAPTER XVI

PORCELAIN

THE manufacture of porcelain has been carried on since the earliest days of which there is any record, more particularly among the Chinese and Japanese. Porcelain differs from other kinds of pottery in consisting of a body of translucent nature which is made by extensive vitrification of the material. It thus resembles glass, though the composition is more complex and the fusion of the materials less complete than in the latter. Complete fusion would necessarily result in the loss of shape of the article and so must be avoided.

There are numerous kinds of porcelain, and the literature connected with them is very extensive ; hence, in the present volume it must suffice to state the chief characteristics of those porcelains which are of commercial importance at the present time and to omit reference to those of merely antiquarian interest.

Hard Paste Porcelain is made largely on the Continent, but not in Great Britain.[1] It consists of a mixture of china clay (kaolin) and felspar or other flux, the proportions of these and any other ingredients being so arranged as to produce a translucent mass at the temperature at which the kiln is fired, this being usually about 1,400° C. (2,550° F.). The body is always prepared in the form of a slip (p. 60), and the articles are shaped in much the same manner as those made of earthenware (Chap. XV), though porcelain is so much

[1] The porcelain evaporating dishes and crucibles used in chemical analysis were formerly imported wholly from Germany. Since the war, they have been manufactured successfully in Worcester, though the British articles have a slightly different composition.

less plastic that greater care has to be taken in manipulating it. The ware is first fired to about 800° C. (a dull red heat) in order to convert it into biscuit and make it porous ; after this it is decorated and glazed in a similar manner to earthenware (*q.v.*), but as the glaze is fired at 1,300 to 1,400° C. (2,550° F.), it is peculiarly difficult to find colours which can be applied under-glaze to hard porcelain. Hence, hard porcelain is usually glazed on a plain white body, the glaze consisting essentially of felspar with sufficient whiting, china clay and flint to make it adhere well to the body and to form a sufficiently glossy glaze. The colours are then applied on top of the glaze (over-glaze, see p .131), but are usually burned at a somewhat higher temperature than is customary for earthenware manufacture.

Vitreous Porcelain is the basis of much French ware ; it forms a glassy mass when in the kiln and is extremely difficult to manipulate on account of its great tendency to distortion. It bears a much closer resemblance to a glaze than to clay ware, having a large proportion of frit in its composition.

China Ware or Bone Porcelain is the principal porcelain manufactured in Great Britain. Its essential ingredients are china clay, Cornish stone and bone ash, the latter material being made by burning the bones of oxen. China ware varies greatly in composition, but a typical one consists of—

Bone Ash	35 lbs.
China Clay	28 lbs.
Cornish Stone	37 lbs.

These materials are converted into slips (though occasionally they are weighed out in the dry state and then converted into a single slip) and a series of cakes (p. 62) is obtained by filter-pressing. The ware is made in a similar manner to earthenware, the glaze being of a similar character and requiring a much lower temperature for burning than does the body. The biscuit is usually burned at about 1,250° C. (2,282° F.) and the glaze at 1,050° C. to 1,100° C. (1,920—2,012° F.). The decoration is usually under-glaze (p. 125) with over-glaze for special colours (p. 131), the colouring being more brilliant than with hard porcelain.

By courtesy of *Messrs. The Worcester Porcelain Co.*

FIG. 29

TURNING PORCELAIN WARE

The properties of china ware are such as to make it excellent in every respect for table ware of all kinds, and although it is sometimes stated that it is more liable to show scratches from knives and forks than does hard porcelain, yet its lesser brittleness and the greater variety of the colours obtainable largely compensate for any doubtful difference in this respect.

Parian Ware is a kind of porcelain which, in the biscuit state, bears a close resemblance to the finest Parian statuary marble. It is made by mixing one part of china clay with two parts of felspar, other ingredients being sometimes added to increase the plasticity or whiteness of the ware. If Parian ware is glazed with a glaze similar to that used for china ware it corresponds very closely to some of the ancient Chinese porcelains and to the Continental hard paste porcelains.

Chemical Porcelain closely resembles hard paste and Parian ware, but is glazed with a leadless felspathic glaze. It is chiefly distinguished by its ability to resist the action of chemicals and sudden changes in temperature, and until recently was manufactured almost exclusively on the Continent. (See the foot-note on p. 134.)

Electrical Porcelain is used for the manufacture of insulators, etc. It is similar in many respects to the hard porcelain, but is usually made from less pure materials, a considerable proportion of plastic clay being used to facilitate the manufacture of articles of specially complex shape. As many of the pieces made of electrical porcelain have to be provided with screws or other attachments which enable them to fit into other pieces of apparatus it is necessary that they should be made with great accuracy and of a material which will not shrink unduly in the burning. For providing the maximum electrical resistance the material used must approach very closely the composition and characteristics of hard porcelain, but for less important work stoneware (p.106) or a material consisting chiefly of steatite is largely employed.

CHAPTER XVII

REFRACTORY GOODS

THE materials used for furnace linings and for other purposes where great resistance to heat is required are termed refractory, though this word is used somewhat loosely. In the strict sense, a refractory article is one which will not lose its shape by partial fusion when heated to a temperature of 1,580° C. (2,786° F.),[1] the heating being at a slow rate and with an ample supply of air. In actual use, the goods required to be "refractory" must also resist the cutting action of dust in the flues, the effect of flames impinging on them, the crushing action of any load to which they may be subjected, and usually they must not be destroyed by unavoidable changes in temperature or by the corrosive action of the contents of the furnaces. It will be readily understood that an article, such as a firebrick, which may be quite refractory in the strict sense mentioned above may not be so when the term is used to indicate durability in use. It is, therefore, of the greatest importance that such terms should be used in a limited sense or that their use should be supplemented by some indication of what they are intended to mean.

The chief refractory articles are furnace and kiln linings (usually made of firebricks or blocks or of the raw material rammed into position), retorts for the distillation of coal or metals, pots used for melting glass, crucibles and scorifiers or roasting dishes.

Materials.—The chief materials used for refractory goods are the *fireclays* found in association with coal,

[1] The temperature stated is an arbitrary one which has become customary on account of its convenience.

though for special purposes these are sometimes mixed with china clay and other materials. The use of *silica* (particularly in the form of *ganister*) is also extending as a convenient material for the manufacture of firebricks, and where specially high temperatures are prevalent under conditions requiring an alkaline material, it is customary to employ magnesia which has been burned at an extremely high temperature. Chrome iron ore is used where a strictly neutral material is required.

The fireclays are plastic and may be worked in a manner similar to other clays, so that they do not need any detailed description here. Silica, magnesia and chrome iron ore are void of plasticity and can only be made into bricks or other simple forms by the addition of a bond ; in the case of silica this is usually lime ; for magnesia a lightly burned magnesia serves the same purpose, whilst the use of tar is customary for bricks of a neutral nature.

Firebricks.—When made of fireclay, bricks are produced by grinding the clay, screening it (p. 51) and then tempering it with water as described in Chapter VIII. Firebricks are usually made by hand as described on p. 71 ; they are dried on a hot floor (p. 85) and burned in kilns with horizontal or down-draught or in a continous kiln (p. 87). Firebricks require to be burned at a temperature much higher than is used for building bricks, though many makers do not burn them as much as is desirable. The purpose for which the bricks are to be used should regulate their treatment in the kilns, firebricks to be used at the temperature of melting steel being burned at or above that temperature, whilst those for a boiler flue may be satisfactory if burned 200° C. (400° F.) lower. The appearance of a firebrick gives but little indication of its value, in fact a clean-looking firebrick is usually one which has not been sufficiently burned to be reliable, and a dark coloured, apparently scorched brick will probably be much less affected by the heat. The only true test of the value of firebricks is by actual use, though much may be done by various measurements of their shrinkage or expansion at various high temperatures.

Silica Bricks are made by grinding silica rock to sand, mixing with lime and water and moulding the paste as described on p. 71. The bricks are dried and burned like fire-clay bricks, but differ from the latter because silica bricks expand when heated in the kiln. If heated for a long time at a sufficiently high temperature further expansion may largely be prevented. For this reason it is necessary to burn silica bricks at a higher temperature than that at which they are to be used.

Magnesia Bricks (often termed "magnesite bricks") are made by burning magnesite until it vitrifies, grinding the product and mixing it with lightly burned magnesia and water so as to form a paste (p. 54). This is made into bricks as described on p. 71, and the bricks are dried very cautiously and are fired to vitrification (about 1,580° C. or 2,876° F. or even higher), usually on top of silica bricks. In the majority of works it is not considered practicable to burn the bricks at so high a temperature, and the kiln is not heated much above 1,410° C. or 2,570° F. Intermittent kilns are almost invariably used in Great Britain, but in Austria, where the largest quantities of magnesia bricks are made, gas-fired kilns are chiefly used, and are far more economical, but require a large and regular output.

Chrome Bricks are made of chrome iron ore, the crushed particles being united with tar or with lime, the process used being similar to that described above for the manufacture of silica bricks.

Properties of Firebricks.—The chief requisite in firebricks is that they shall prove durable when used under the conditions prevailing in the various furnaces and kilns in which they are employed. For this, they must be highly refractory, that is, resistant to a high temperature, and at the same time they must not be unduly attacked by the materials with which they are brought into contact. They must also remain unaffected by sudden changes in temperature such as are unavoidable in the ordinary manipulation of a furnace or kiln. The refractoriness of the bricks is largely dependent on that of the raw materials from which they are made, it being an invariable fact that the bricks cannot be so resistant to heat as are the raw materials considered quite separately. The action of the material with which the bricks come in contact may be purely physical, such as the abrasive action of the solid contents of the furnace rubbing the surfaces of the bricks; it may be due to the cutting action of the gases in the furnace, and, above all, it may be due to the corrosive action of the dust from the fuel or the slagging action of the contents of the furnace. Most slags are highly basic in character, and these combine with the firebricks made of clay or silica, the base in the slag uniting with the acid clay or silica in the bricks and forming fusible compounds, which result in the destruction of such bricks. As this corrosion is due to a chemical action it can only be avoided by using firebricks made of a neutral or basic material with which the basic contents of the furnace can have no chemical reaction. Hence, for the most basic charges, the furnaces should be lined with magnesia or chromite bricks, the latter being usually too costly for this purpose. It is not always necessary to line a furnace throughout with the same kind of bricks; indeed it is usually better to employ basic (magnesia) bricks in the lower part where the action of the slag is strongest and firebricks made of clay in the upper parts where the conditions are entirely different. As magnesia and fireclay or silica bricks react on each other when heated constantly to very high temperatures a course or layer of neutral (chromite) bricks should be built between them.

For regenerators, annealing furnaces, and heating arrangements, other than those used for smelting metals, it is necessary to pay the closest attention to the conditions prevailing and to select bricks which will best withstand those conditions. It not infrequently happens that mere resistance to high temperature is less important than ability to withstand sudden changes in temperature or resistance to crushing under a heavy load. It is seldom that good firebricks fail on account of insufficient resistance to heat (refractoriness); their destruction is usually brought about by corrosion, sudden heating or cooling, abrasion or some other condition dependent on the furnace and largely to be overcome by the use of bricks with appropriate qualities other than mere refractoriness. In other words, it is a great mistake for purchasers of firebricks to lay the chief stress on refractoriness; rather should they consider the other properties required and lay the chief stress on these.

Blocks.—For some parts of furnaces it is necessary to use large blocks of special shape. These are usually made of fireclay or other refractory material in precisely the same manner as terra-cotta (p. 98) but they are burned at the same temperature as firebricks, viz., somewhat above the highest temperature to which they are likely to be exposed when in use. This is necessary in order that they may not shrink or expand unduly under the condition to which they are exposed.

Unless this precaution is taken, the change in volume of the blocks may endanger the whole structure of which they form a part.

Retorts.—In the manufacture of illuminating gas from coal and in the distillation of zinc and some other materials it is necessary to use retorts. These are vessels, made of a refractory material, which are closed at one end and a door at the other; they also have an outlet through which the volatile material may pass away. These retorts must be impervious to gases and must be capable of rapid heating and cooling. They are usually made of fireclay with which a considerable proportion of burned fireclay (*grog*) has been mixed so as to produce a material of coarse texture, the surfaces of which are made of finer and, therefore, denser material. By this means a material is produced which meets the requirements of the users of retorts, the chief difficulty being to adapt it to meet the peculiar local conditions which obtain in certain works.

Retorts are made on special tubular drums, a small portion being built at a time and allowed to become stiff before a further portion is added. The method of manufacture is similar to that of terra-cotta (Chap. XII), but is much slower on account of the size of the retorts. The smaller retorts are often made in a machine similar to those used for drain-pipes (p. 107); one end being afterwards closed by fitting a slab of clay to it.

When completed, the retorts are kept in slightly warmed rooms where they are protected from draughts until quite dry. This requires some weeks, and it cannot be shortened much without serious risk of cracking the retorts. Sometimes the retorts are glazed internally with a felspathic glaze before being sent to the kiln; this glaze tends to make them slightly more impervious at first, though it very soon cracks and peels away with the repeated heatings and coolings. Retorts, like firebricks, require to be burned at a higher temperature than that at which they are to be used, so that they may not become distorted in shape. It will generally be sufficient if they are burned at 1,300° C. or 2,372° F.

Crucibles.—When materials have to be melted in comparatively small quantities the operation is usually carried out in crucibles. These vessels must, therefore, be made of a material with sufficient refractoriness and at the same time sufficient resistance to the corrosion caused by the contents and enough strength to enable the crucible with its contents to be handled readily with crucible tongs. Crucibles can be heated gently and steadily, but they are necessarily cooled very rapidly, the crucible being withdrawn from the furnace and its contents poured out rapidly. To enable it to withstand these sudden changes in temperature the addition of graphite or plumbago is frequently made to the clays used in manufacturing the crucible; this addition increases the rate at which heat can pass through the walls of the crucible, and at the same time enables it to be heated and cooled with great rapidity.

Crucibles are usually made of a mixture of several fireclays, as these produce better results than when only one clay is used. In addition to the clays a proportion of burned fireclay (*grog*) or sand is sometimes added, and, for plumbago crucibles, graphite is also added, as stated above. The materials are carefully reduced to powder, mixed with water to form a stiff paste and then mixed with great care and thoroughness, as uniformity of texture is of very great importance. The paste is made into the required shape either by throwing (p. 102) or, more commonly, by one of the methods of moulding used in the manufacture of earthenware

(Chap. XVI). The crucibles are dried very carefully and are afterwards burned if they are to be sent a long distance, but if they are to be used in the works in which they are made—a very common practice—they are "burned" by placing them in the furnace in which they will be used and heating them very carefully. When the crucible is red hot it may be used by putting in a portion of the material to be melted, the charge and the crucible then both being heated at the same time. The temperature to which crucibles are heated in order to facilitate their transport is seldom above a bright red heat, the precise temperature being a matter of small importance so long as the crucibles are made sufficiently hard and strong to stand moderately rough usage.

The durability of crucibles depends largely on the purposes for which they are used; for some purposes a crucible may be used forty times or more; for others each fresh charge requires a new crucible. Hence, it is impossible to state what should be the behaviour of a crucible unless its use is known.

Glass-House Pots are a specially large form of crucible used for melting together sand, lime, salt cake, and other materials used in the manufacture of glass. They require to be of large capacity and must be made of highly refractory fireclay to which some grog has been added, the mode of manufacture consisting in building up the paste into the desired shape by hand, with or without the use of a wooden mould. Owing to the large size of the pots they can only be made piecemeal, the height being increased about 6 in. per day. The drying of glass-house pots must be carried out very slowly, six months or more being usually required; if the drying is hurried, the pots are almost certain to crack. The pots are burned in single, intermittent kilns to a temperature just sufficient to make them durable in transport; the final heating is given in the glass-maker's furnace just before the pots are used.

The materials used for making glass are highly corrosive in their action on clay, so that the pots must be made of fireclay and grog of such properties that they will withstand the high temperature of the glass-furnace and at the same time will not be unduly corroded by the glass materials. Hence, the pots must be made of a clay rich in alumina, the particles being carefully graded as to size so as to give a porous interior and a fine exterior surface to the pot. The loss caused by the accidental breakage of a pot when in use is so serious to the glass manufacturer that the production of the pots is limited to firms of good reputation in this branch of clayworking.

CHAPTER XVIII

PORTLAND CEMENT

ALTHOUGH few people realise it, Portland cement, and the many natural cements which are allied to it, are all clay products, and are composed essentially of some form of clay which has been heated with some compound of lime. Hence, as clays are alumino-silicic acids, this group of cements is composed of various lime alumino-silicates. There have been many investigations as to the true nature of Portland cements, some of these studies being rendered quite abortive because the investigators did not know sufficient of the nature of clays and clay compounds; others appeared to show that Portland cement is a complex mixture of aluminates and silicates of lime, and it is only quite recently that it has been definitely recognised that the true composition of Portland cements is that of a lime alumino-silicate, as stated above. Some investigators have used the term *alite* to represent these alumino-silicates, and this term is very convenient, but is misleading unless it is clearly understood that it relates to a group of alumino-silicates of similar yet by no means identical composition and not to a single substance common to all Portland cements. It is the failure to recognise this distinction which has made it so difficult for many investigators to draw correct conclusions from their experiments.

Once it is clearly understood that the Portland cements are definite compounds of clays and lime it is comparatively easy to understand their properties and the manner in which they are prepared; it is also easy to understand why clays of different natures produce cements of slightly different characteristics.

Materials.—The raw materials used in the manufacture of Portland cements are of two groups: the first consists of acid materials and include *clays, shales* and *clayey rocks*. The second group consists of basic materials such as *chalk*, *limestone* and other naturally occurring lime compounds which produce lime when heated to a sufficiently high temperature. Between these two groups is a third consisting of mixtures of the materials in both the first and second groups, such mixtures being known as *marls, clayey limestones* or *limey clays* according to the relative proportions of lime and clay which they contain. The materials in this third group include those natural mixtures which produce a cement of medium quality when the material is heated to a sufficiently high temperature, such cements being known as Natural Cements. They are not so valuable as true Portland cements, because the natural mixtures are seldom so accurately proportioned as the artificial mixtures from which true Portland cement is made.

Manufacture.—There are two distinct methods of making Portland cement, known as the "wet" and "dry" processes respectively; some firms also use a combination of the two which they term the "semi-dry" process.

In the *wet process* the clay and chalk are treated in a wash mill and are there mixed in suitable proportions, sufficient water being added to make a thin slip or slurry (see p. 60). The slurry is run through a fine grating into another mill or tank where it is tested in order to ensure it containing the correct proportion of chalk and clay. The solid matter is then allowed to settle and the clear water is run off, the thick paste being allowed to become stiff enough to walk upon. This paste is then cut up into cakes or lumps and is passed through a mixer in order to make it uniform in composition; after this it is dried on a hot floor heated by waste gases from the kiln. The dry lumps of material are fed into the kiln and are burned until they vitrify, the semi-fused mass or *clinker* being afterwards ground so as to form the Portland cement.

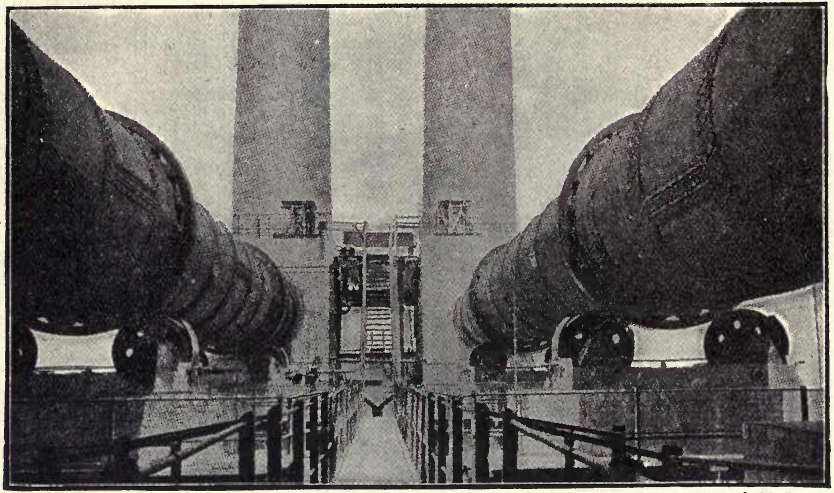
In the *dry process*, the shales or other indurated clay and limestone are dried and are then crushed to fine powder in ball mills which consist of a rotating cylinder partly filled with flint pebbles or steel balls. These balls fall on the material as the cylinder revolves and thereby crush it to powder, the latter escaping through holes in the flat ends of the mill. It is usually necessary to pass this somewhat coarse powder into a second longer mill, termed a tube mill, in which the reduction to fine powder is completed. The raw meal thus produced is placed in silos or storage bins in order that it may be tested and its composition adjusted if necessary. The material is withdrawn from the bins as required, mixed thoroughly in a trough mixer and is then taken to the kiln and burned to clinker, the clinker being afterwards crushed to a fine powder, which forms the cement.

There is a great difference in opinion as to the relative merits of the wet and dry processes; in some cases either may be used equally well, in others the fact that one of the materials to be used requires crushing makes it essential to use part of the "dry" process and generally makes it desirable to use it throughout. Many of the arguments which have been published concerning both processes are entirely unreliable, and the present practice is to rely more on the nature of the materials than on any supposed advantage in either process. In either case, thorough mixing of the finely divided materials is essential, and no pains should be spared to secure this.

The kilns used for burning the clinker are now almost invariably of the rotary type, as they are much more economical in labour and fuel than were the older types of kiln, though the product obtained from the latter was equally as good in quality when the same methods of preparation were used. The rotary kiln (Fig. 30) consists of a slightly sloping cylinder 60 to 110 ft. in length and about 6 ft. in diameter, which is rotated slowly whilst in use. The raw meal is fed in at the upper end and the fuel is introduced at the lower one. Hence, the material gradually increases in temperature in its passage through the kiln, and when it emerges from it the clinker is white hot. The cooling of the clinker is effected by passing it through another similar, but much shorter, tube, through which is passed a current of air on its way to the kiln. This arrangement simultaneously heats the air and cools the clinker so that the air is in an excellent condition for burning the fuel. The kiln is heated with finely ground coal dust, which is blown into it with a current of hot air, producing a long and intensely hot flame of great heating power.

It is necessary that the material should be uniformly heated, as under-burned clinker is of small value, and a little of it may easily spoil a large batch of cement. Over-burning is difficult, so that if care is taken that all the clinker has been heated to at least 1,410° C., there will be little liability to errors in burning.

The clinker produced is of a dark grey colour ; it is extremely hard and full of minute pores. To make it useful it must be ground to an extremely fine powder in a tube mill or in some other form of fine grinding-mill



By courtesy of *Messrs. Newell & Co.*

FIG. 30

ROTARY KILNS FOR CEMENT

in which little loss of dust will occur. It is usual to blow a little steam into the grinding-mill and to add about 1 per cent. of gypsum; this treatment extends the time taken in setting when the cement is mixed with water and thus makes it more useful, as rotary kiln cement which has not been so treated sets almost instantaneously. The clinker must be ground so finely that not more than 3 per cent. of it will remain on a sieve with 76 holes per linear inch, and not more than 18 per cent. on a sieve with 180 holes per linear inch, the test being conducted on 4 oz. of material shaken on the sieve for fifteen minutes. This test and others relating to the characteristics of Portland Cement are contained in the British Standard Specification which is adopted by all official bodies and by many architects in the British Empire when ordering cement.

The ground cement is stored in silos and is put into bags holding 100 lbs. each when required for use. The manufacture to be profitable must be carried out on a very large scale, as the process must be worked continuously day and night. Hence, the prospectuses issued by some company promoters with respect to small works for this industry are quite misleading and are based on ignorance of the conditions required. In competition with modern firms it is practically impossible to sell cement of inferior quality, so that the industry is entirely unsuited to a man with only a moderate amount of capital.

Properties.—The essential property of Portland cement is that it shall, when mixed with a suitable proportion of water, form a paste which sets rapidly to a hard mass, producing a good cement, the hardness of which increases at a satisfactory rate with the progress of time. These properties are checked in the British standard specification by imposing limits on the time required for setting, and on the tensile strength of the cement when freshly made, and after seven and twenty-eight days respectively, though the test on freshly-made cement is seldom used. Various tests are also imposed in which an attempt is made to age the cement artificially by boiling it in water, etc. Many tests of Portland cement fail because they are applied to the neat cement, whereas they really ought to be applied to a mixture of sand and gravel or other aggregate such as is used for some structural purpose. When this is done, the results of the tests are far more comparable with the behaviour of structures in which cement is used, and curious anomalies—such as a mixture of cement and sand giving a higher tensile strength than the same cement when used alone—are avoided.

Concrete.—Concrete is a material made by mixing sand and gravel with water and Portland cement so as to form a pasty mass which gradually hardens and forms an artificial stone of great durability. Its great advantage consists in the ease with which it may be used in the erection of massive structures in localities where stone would be far too costly and would take too long to prepare. Concrete is commonly spoken of as consisting of three ingredients (i) Water, (ii) Cement, and (iii) Aggregate. The last-named term includes any sand and coarse material which may be used, the particles of aggregate being united by those of the cement. Aggregates are formed of stone, gravel, pebbles, slag, and a variety of other materials of a stony nature. The particles of aggregate are relatively coarse, pieces as large as hens' eggs being commonly used for foundations and walls, the smaller particles being used for finer work, paving blocks, walls, etc.

The proportions of aggregate, cement and water required for concrete depends on a variety of factors, including the size of the particles in the aggregate, the purpose for which the concrete is to be used and the size of the blocks or other articles to be made. It is, therefore, impossible to give details within the limits of the present volume, and the reader desiring them should consult one of the books mentioned on page 158.

Reinforced Concrete is concrete which is so arranged as to surround a skeleton of steel work, the latter being in the form of bars of special shape, wire netting or perforated sheet. Plain concrete has a remarkable degree of resistance to compression, but is relatively weak under tension ; this weakness is entirely avoided by the use of reinforcement, a very small proportion of steel being required for the purpose. The use of reinforced concrete has therefore rapidly extended during recent years, and it is now employed in the construction of a great variety of buildings, bridges, foundations and other structures. Great ingenuity is frequently exercised in the shaping and arrangement of the reinforcing metal in order to reduce the amount required to a minimum whilst still retaining ample strength to resist all probable stresses (see p. 158).

CHAPTER XIX

ULTRAMARINES AND OTHER CLAY PRODUCTS

THERE is a considerable number of materials used for a variety of purposes in which clay is either the raw material from which the products are made or the commercial products are in themselves some form of clay, though not readily recognised as such. It is convenient to group the more important of these materials together in the present chapter.

Ultramarines are well-known pigments of a characteristically blue colour [1] which were formerly obtained from the blue mineral *lapis lazuli*, but are now prepared artificially. The artificial ultramarines are prepared by heating a mixture of china clay (p. 16), sulphur and carbonate of soda to a red heat and carefully washing the blue pigment until it is free from all impurities. The intense blue colour is characteristic of the material and is not due to a colouring substance as was at one time supposed ; in all probability, the colour is due to the relative arrangement of the atoms composing the ultramarine. The ultramarines form part of a large group of alumino-silicates containing sulphur in a peculiar state of combination ; these salts usually contain sodium as the predominant metal, and precisely similar compounds can be produced with silver, lead or zinc in place of the sodium, though these other compounds are not of commercial value as pigments. It is, therefore, important to remember that the ultramarines form a group of compounds and not merely

[1] Green, red and white ultramarines are known, but are of insignificant commercial value.

one particular chemical; this explains differences in the colour and properties of ultramarines from different sources, and renders it possible to speak of green and white ultramarines without committing an error.

Ochre is a variety of clay containing a considerable proportion of iron oxide to which its colour is due. This iron oxide may or may not be in the free state; in the better qualities of ochre it appears to be in the form of an easily decomposed alumino-silicate, the composition of which is by no means understood.

The yellow ochres are easily darkened and made into brown ochres by heating to redness; this appears to decompose some of the iron compound setting iron oxide free. Some natural ochres appear to have been exposed to heat sufficiently to effect a partial decomposition in this manner; such ochres contain a mixture of clay and iron oxide. In some cases, the proportion of free iron oxide is so large that the material bears a closer resemblance to iron ore than to ochreous clay.

Various ochreous pigments imported from abroad are known by special names; thus *Lemnian earth* is obtained in the Island of Stalimene; *Armenian bole* is imported from Armenia; *sienna* comes from the Italian town of that name, *burnt sienna* being the same material which has been heated to a dull red heat; *umber* is an indurated ochre chiefly obtained from Cyprus, and after being heated to redness and carefully levigated, it is largely used under the term *burnt umber* as a pigment and oil-dryer.

A variety of ochre is also obtained in Dorset by washing ball clays and carefully retaining the coloured residues.

For use as pigments, all these materials must be carefully ground to an impalpable powder, after which they are treated with water to separate the coarser and useless particles ; the washed product is then carefully dried and is sometimes subjected to a further grinding to ensure its being of the requisite fineness.

Fuller's Earth and Lithomarge are naturally occurring minerals which bear a close resemblance to china clay (p. 16) and for many commercial purposes the latter may be used to replace them ; often with advantage, as it is usually finer and more uniform in texture. True fuller's earth is devoid of plasticity and in this respect, it differs from china clay and lithomarge, but by heating china clay slightly it may be made increasingly to resemble fuller's earth. Both lithomarge and fuller's earth are used to remove grease from woollen cloths and as the basis of many toilet preparations. The finer and less plastic the materials and the greater their power of absorbing or combining with grease, the better their quality ; this is often improved by lightly baking the earth before use.

A SHORT LIST OF BOOKS ON CLAY AND CLAY PRODUCTS

	Author.	Publisher.
ORIGIN AND VARIETIES OF CLAYS.		
British Clays, Shales and Sands.	A. B. Searle	C. Griffin & Co., Ltd.
The Natural History of Clay	A. B. Searle	Cambridge Univ. Press
The Silicates	W. & D. Asch	Constable & Co.
WINNING AND PREPARATION OF CLAYS		
Clayworker's Handbook.	A. B. Searle	C. Griffin & Co., Ltd.
Modern Brickmaking.	A. B. Searle	Scott, Greenwood
Treatise on Ceramic Industries.	E. Bourry	,,
BRICKMAKING		
Bricks and Tiles.	E. Dobson & A. B. Searle	Crosby, Lockwood & Co.
Modern Brickmaking.	A. B. Searle	Scott, Greenwood
Hand Brickmaking.	A. E. Brown	Clayworker Press
TILE-MAKING		
Bricks and Tiles.	Dobson & Searle	Crosby, Lockwood & Co.
Roofing Tile Manufacture.	E. L. Raes	Maclaren & Son
Treatise on Ceramic Industries.	E. Bourry	Scott, Greenwood
TERRA-COTTA		
Terra-Cotta Modelling.	P. Hasluck	Cassell & Co.
EARTHENWARE AND PORCELAIN		
Earthenware Manufacture.	E. Sandeman	Virtue & Co.
Treatise on Ceramic Industries.	E. Bourry	Scott, Greenwood
English Earthenware and Stoneware	W. Burton	Cassell & Co.
Porcelain	W. Burton	Cassell & Co.
REFRACTORY MATERIALS		
Refractory Materials (in the press)	A. B. Searle	C. Griffin & Co., Ltd.
PORTLAND CEMENT & CONCRETE		
Cement, Concrete and Bricks.	A. B. Searle	Constable & Co.
Portland Cement.	D. B. Butler	E. & F. Spon
Reinforced Concrete	B. E. Jones and others	Cassell & Co.

NOTE.—A fairly complete list of books dealing with the claymaking industries is published in the Appendix to *The Clayworker's Handbook,* by A. B. Searle (C. Griffin & Co., Ltd.) price 6s. Many of the books therein mentioned are in French or German, the chief technical works in the English language being given in the Table above.

Much additional information may also be obtained from the following Journals—

Title.	Publisher.
The British Clayworker.	Clayworker Press, 43 Essex Street, Strand, W.C.
The Brick & Pottery Trades' Journal.	Maclaren & Sons, Ltd., 38 Shoe Lane, E.C.
The Pottery Gazette.	Scott, Greenwood & Son, 8 Broadway, Ludgate Hill, E.C.

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