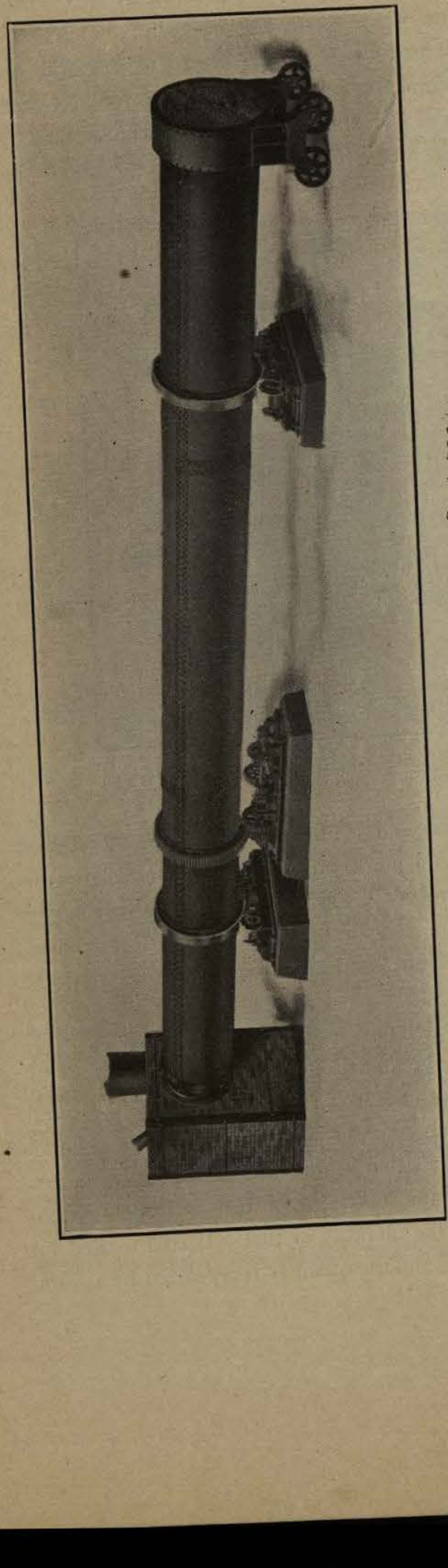

FIG. 231.—Rotary Kiln. (See p. 713.)

conveyor running at changeable speed. The heat in the kiln is so intense that the coal burns as a gas without apparent smoke or cinder. The proper temperature, which is said to be 2700° to 3000° Fahr., is determined by the appearance of the burning stone. At a certain point in its descent the material becomes semi-vitrified and forms into irregular balls or clinkers, which roll around and finally fall out red-hot at the lower end in particles, most of which range in size from sand to 1-inch diameter. The clinker, when properly burned, is of a greenish black color with a faint glisten, and contains but few large pieces. It slightly resembles in appearance the clinker often found among the ashes of hard coal.

The output of a rotary varies with the length and diameter from 150 to 200 barrels per 24 hours for a 60 foot kiln to 1000 to 1200 barrels, for a 158 to 200 foot kiln with a smaller coal consumption per bbl.

The clinker, after being cooled in some form of cooler, is crushed by passing between horizontal rolls

or through some other form of crusher, and is then ready for the fine grinding, or, if desired, it may be stored either out of doors or under cover until needed. Strangely enough, wetting the cinder does not injure it provided it is dry when it enters the fine grinders.

The fine grinding is generally accomplished by passing the clinker through ball mills and then through tube mills, or by a single operation in such machines as the Griffin, Kent or the Fuller Mill. A section of a ball

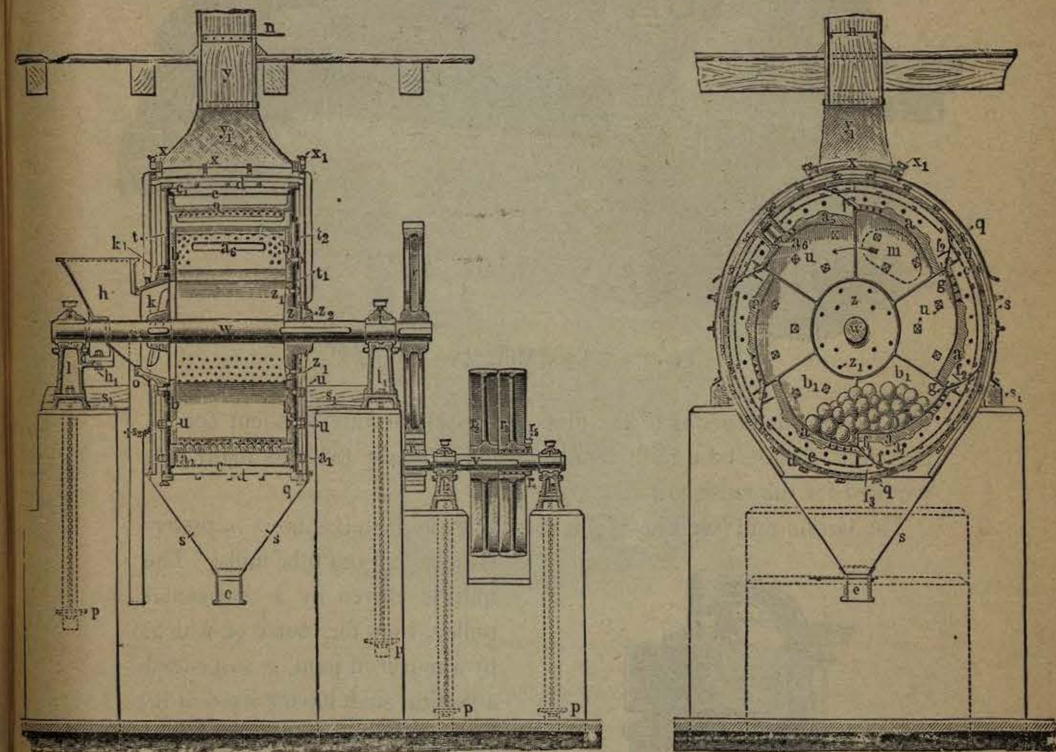

FIG. 232.—Ball Mill. (See p. 715.)

mill is shown in Fig. 232. It consists essentially of a cylindrical drum, lined with castings of hard, tough steel, and containing forged steel balls 8 or 10 inches in diameter. Rotation of the drum grinds the stone or clinker between the balls and the plates, and the powder passes through sections of screens — which for clinker have usually 20 to 28 meshes to the linear inch — into the hopper below. A single ball mill, such as is shown in sketch, running on clinker, should give an output of, say, 5 500 to 7 500 pounds per hour.

A tube mill (see Fig. 233) consists of a long horizontal cylinder filled nearly to its axle with flint pebbles imported from Europe, which average about 2 to 3 inches in diameter. The cement is ground by rolling around with the flints. It is then thrown by centrifugal force against the screen, which regulates the fineness of grinding and prevents the passing of pieces of flint. A tube mill which passes, say, 250 barrels of cement per day,

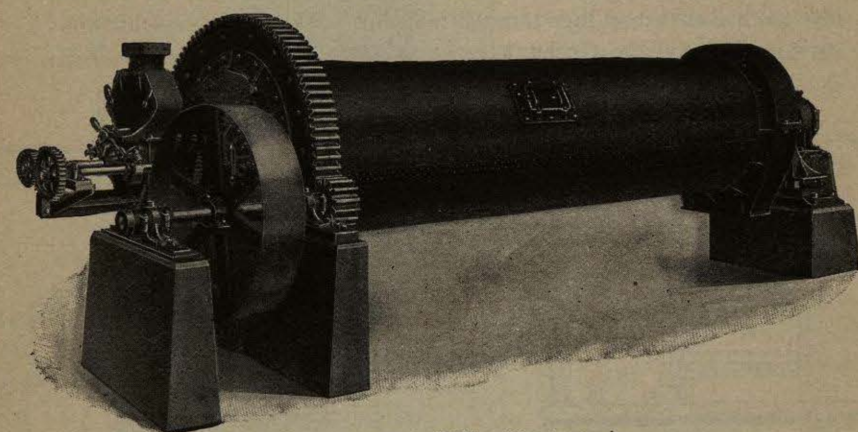

FIG. 233.—Tube Mill. (*See p.* 715.)

will require the renewal of the flint pebbles at the rate of about 600 lb. per week. More tube mills than ball mills, usually twice as many, are required for the finish grinding.

The Griffin mill (see Fig. 234) is used by many manufacturers in preference to ball and tube mills. The mill is driven by a horizontal pulley, from the center of which, by a universal joint, is suspended a vertical shaft having fixed at its lower extremity a crushing roll, which revolves on its axis at a speed of about 200 revolutions per minute, and also rotates by centrifugal force against the ring or die where the pulverizing is accomplished. The material to be ground passes first into the pan below the crushing roll, upon the under side of which are shoes or plows which stir it up and force it up between the roll and the die.

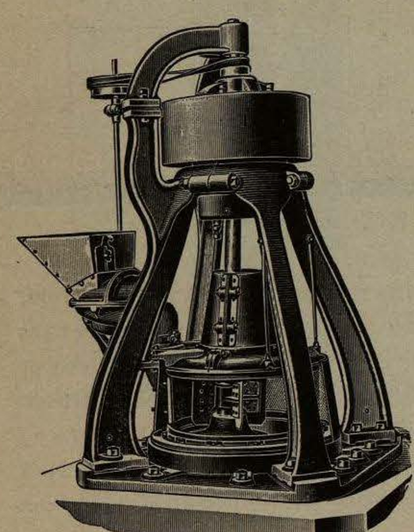

FIG. 234.—Griffin Mill. (*See p.* 716.)

The cement or stone is so finely powdered that, held in suspension by the moving air, it passes through a cylindrical screen above the roll, and falls through slots in the circumference of the pan into the hopper below, to be carried off by a conveyor. The screen in mills for grinding clinker is 30 to 32 mesh to the linear inch but as it is placed vertically, it lets through only cement of such fineness that 75 to 80% of it will pass a 200-mesh sieve.

The Kent pulverizer, shown in Fig. 235, which is used in a few plants,

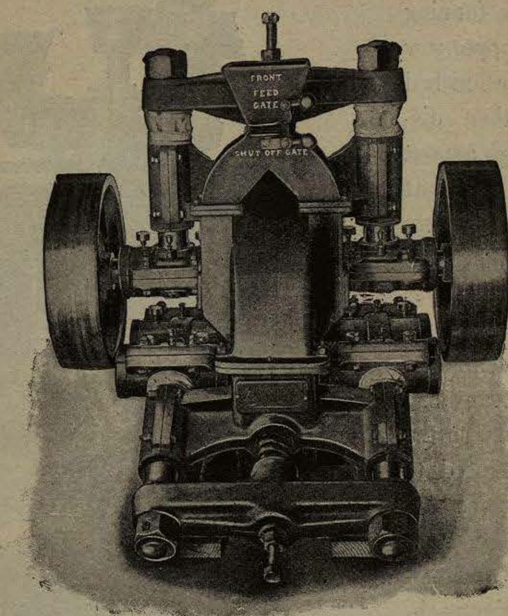

FIG. 235.—Kent Mill (*See p.* 717.)

consists essentially of an upright circular case containing within it three rolls surrounded by a revolving ring. The material is ground by passing between the internal circumference of this ring and the rolls, which are pressed against it by springs.

The Fuller-Lehigh mill, illustrated in Fig. 236, has come to the front during the past few years as a fine grinder for grinding coal, raw material and clinker. The material to be reduced is fed to the mill from an overhead bin by means of a feeder mounted on top of the mill. This feeder is driven direct from the mill shaft by a belt running on a pair of three-step cones, which permits the operator to accommodate the amount of material entering the mill to the nature of the material being pulverized.

The grinding is done by means of four unattached steel balls 12 inches in diameter, which are propelled by four equidistant horizontal arms or pushers radiating from a vertical central shaft. The material discharged by the feeder falls between the balls and the die and is reduced to a finished product in one operation. Above the die and the balls and attached to the yoke propelling the balls, is a fan with two rows of fan blades, one above the other. The lower set of blades lifts the finished product from the pulverizing zone into the chamber above the die, where it is held in suspension until it is floated out through a screen by the fanning action of the upper row of blades. The finished product is then discharged through a spout which may be placed at any one of four quarters of the mill. When the mill is in operation, it is continually handling only a limited amount of material at any one time. As soon as the material is reduced to the desired fineness, it is lifted out of the pulverizing zone and discharged from the machine.

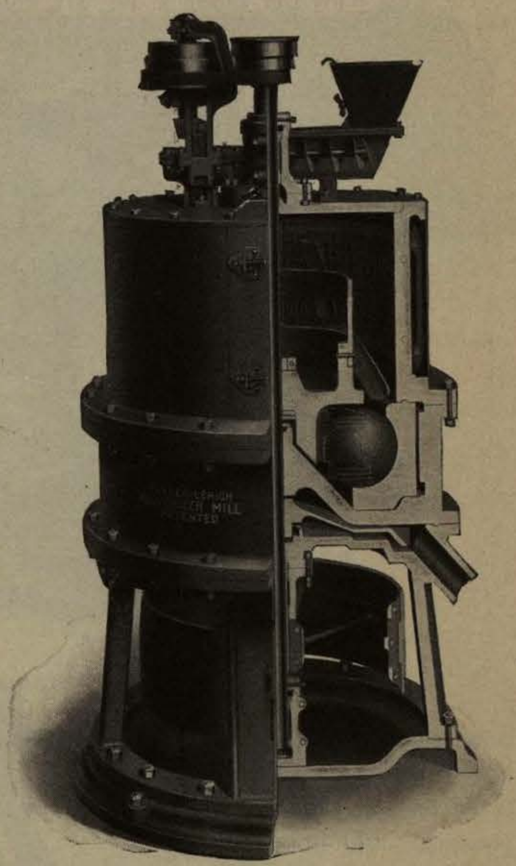

FIG. 236.—Lehigh-Fuller Mill. (*See p.* 717.)

It is customary to store the cement in bulk and weigh it out into bags or barrels as required for shipment. An automatic weighing machine similar to that shown in Fig. 230, page 713 (except that it is single instead of double), is a convenient apparatus for bagging. With this machine a weighing gang consists of three men. The nominal capacity of a single machine is 3 000 bags in ten hours, and the authors have known as many as 3 900 bags to be filled in this time.

In outlining the cement machinery, no reference has been made to the methods for conveying the material from one machine to another. Bucket

conveyors, belts and spiral conveyors are all more or less used. A spiral conveyor is a helical blade on a revolving shaft, set in a square or circular trough or tube of larger size than the spiral, so that the material packs around the circumference, and the blade comes in contact only with the powdered material.

Plaster of Paris (calcium sulphate $CaSO_4$), or gypsum ($CaSO_4 + 2H_2O$) the same substance in crystalline form, is an important addition to cement as a regulator of its setting, and from 1 to 2% is used in nearly all Portland cement manufactories. The gypsum must be added after the calcination and before the final grinding, in order to insure the proper result

The laboratory of a cement plant is an important feature. Not only must the chemical composition of the raw materials and the finished product be analyzed (see Appendix I) at frequent periods, but the cement must be mechanically tested for fineness, time of setting, tensile strength at seven and twenty-eight days, and, perhaps most important of all, for soundness. Most manufacturers use some form of the accelerated or hot test. This is not only due to the fact that many engineers require the cement to pass an accelerated test for reception, but because the chemists in the cement factories consider this test of great value in checking up the quality of cement.

Wet Process with Rotary Kilns. The rotary or Ransome kiln was first used in England on wet materials Rotaries have been widely, in fact almost universally, adopted in the United States for calcining dry materials, and more recently this field has been extended to use with slurry containing as much as 40% of water, which is pumped into the end of the rotary and dried by the same flame used for calcination. With kilns of ordinary length, Mr. Henry S. Spackman states* that at least 25% more fuel is required for burning than with dry materials, and the temperature of the gases in the chimney is about 400° Fahr., one-third to one-half that from dry kilns. The product per kiln, according to Mr. Spackman, is not much more than 100 barrels per kiln, or about one-half the output with dry materials.

Higher production than this has been attained by lengthening the kilns so as to utilize more thoroughly the heat of the flame. Lengths of 70 to 100 feet are used, or a cylindrical kiln about 60 feet in length and 6 feet in diameter, lined with firebrick, is connected at its upper end with an independent drying tube 40 to 50 feet long of slightly smaller diameter and with no lining. A kiln 6 feet in diameter by 60 feet long, with a 54-inch by 50-foot dryer extension, working on wet materials, has been known in certain cases to give an average capacity of from 135 to 140 barrels per day.†

*Proceedings Philadelphia Engineers' Club, April, 1903.
†Statement of Allis-Chalmers Co. to the authors.

In the United States the raw materials most commonly employed in the wet process are marl and clay. The marl as it comes to the mill is broken up in some form of a disintegrator. The clay is dried and pulverized and is then mixed with the marl, which is about of the consistency of thick cream, in a pug mill, or an edge-runner. (See Fig. 237.)

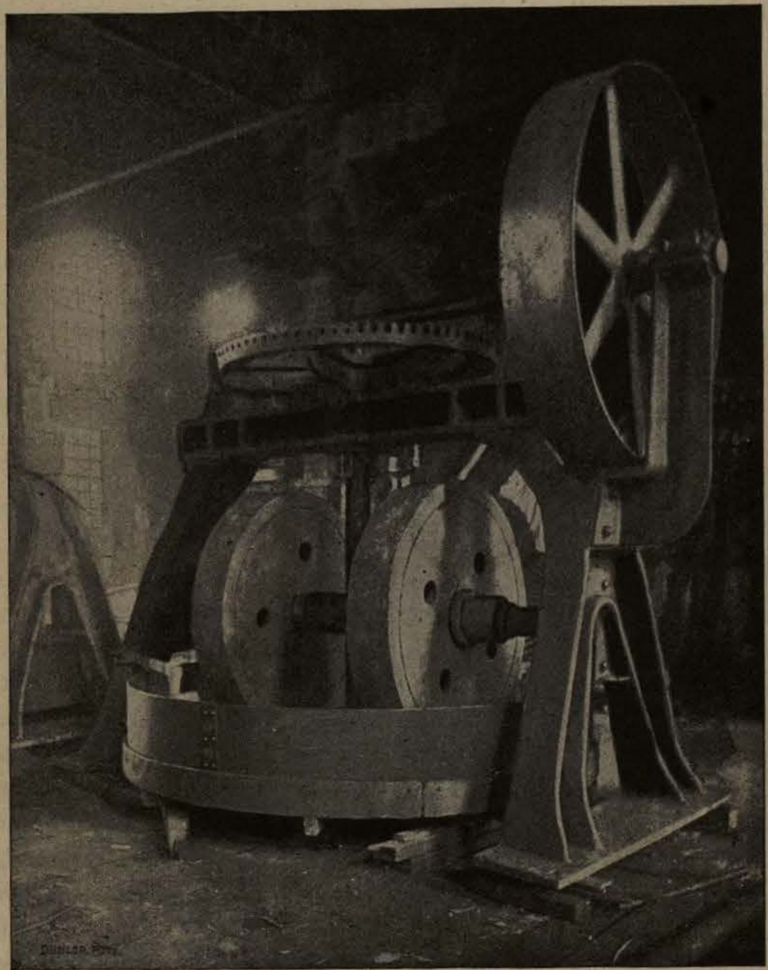

FIG. 237.—Edge Runner. (*See p.* 720.)

In some cases the clay is ground and water is added to it before mixing with the marl.

The mixed materials must now be ground wet before burning. This is often accomplished in mill stones, consisting of a pair of horizontal

stones the upper one of which revolves upon an upright shaft, or in wet tube mills closely similar to that shown in Fig. 233 on page 716.

From the mills, it may be run into tanks, where it is sampled and its chemical composition exactly determined, and from there pumped into the ends of rotary kilns, which, as stated above, are usually made longer than those used in the dry process.

Centrifugal pumps may be employed for conveying the wet material, or if it is too thick for these to handle, plunger pumps may be resorted to. A more recent system of handling is by compressed air.

After calcination the treatment is similar to that in mills where dry raw materials are used.

Stationary Kilns. Before the introduction of rotary or revolving kilns all cement was burned in stationary kilns. Stationary kilns are of two general types: (1) intermittent kilns, which are completely charged and then burned, and (2) continuous kilns, where the fire is maintained continuously and the exhaust heat used to dry and heat the raw materials before burning them.

The most common form of intermittent kiln is the *Dome* or *Bottle Kiln.* This consists of a single shaft into which alternate layers of moist bricks of cement slurry and coke are placed by hand and burned. After cooling, the clinker is drawn out by hand through a door at the bottom, picked over to remove under-burned clinker, — which is of a yellowish shade instead of black, — and clinker which has fused to fragments of the firebrick lining.

The *Johnson Kiln* is a more economical form of intermittent kiln. The slurry is placed in chambers, and dried by the exhaust gases from the burning of the previous charge before being placed in the kilns.

Of the continuous kilns, the *Hoffman Ring Kiln* consists of several chambers or furnaces around a central chimney. As the material in one furnace is burned, the heat passes around through the other furnaces so as to raise the temperature of the bricks in them and utilize the exhaust heat.

In the *Schoefer Kiln,* which is also of the continuous type, the bricks and fuel are loaded from time to time into the upper end of the shaft, and pass down, increasing in temperature, through the flame, where the area is contracted, to be cooled below and drawn out at the bottom.

The *Dietzsch Kiln* is of a somewhat similar type of construction, except that hand-labor is required in passing the dried material into the heating chamber.

Comparison of Rotary and Stationary Kilns. Mr. Frederick H. Lewis* compares the three classes of kilns as follows:

Quantity of Fuel

Intermittent kilns	15 to 30 bbls. per day
Continuous shaft kilns	40 to 80 bbls. per day
Rotary kilns	120 to 250 bbls. per day

Fuel in Terms of Clinker Produced

Intermittent kilns require	25 to 35% of fuel (coke)
Continuous shaft kilns require	12 to 16% of fuel (coal)
Rotary kilns require	22 to 40% of fuel (coal)

The chief difference in cost between rotary and stationary kilns is for labor. In a rotary plant one sees the machinery running with only an occasional attendant, as no handling of the materials is required from the time they enter the mill until the cement is packed in bags or barrels for shipment. In the stationary kiln plant, even if brick machines are used for molding the slurry, a great deal of hand labor is required, as the kilns must be loaded and emptied by hand. Mr. Lewis estimates the labor cost with continuous kilns to range from three to five times the cost with rotaries.

NATURAL CEMENT MANUFACTURE

The process of manufacture of Natural cement consists, in brief, of burning a natural argillaceous limestone at low heat and grinding it to powder. The stone used in England is very soft, in fact nearly as disintegrated as marl.

Raw Material. Many of the limestones used for Natural cement contain a high proportion of magnesia and an excess of clay, while others are nearly free from magnesia. It must be calcined at a temperature much below that required for Portland cement or it will fuse to a slag which after grinding has no hydraulic properties. Suitable formations occur in many parts of the United States, one of the most noted being that found in the region of eastern New York where Rosendale cements are made. Sometimes the stone is taken entirely from one ledge, while in other cases mixtures of two strata are employed. Little attention is paid to the analysis of the rock, as there is a wide range in the required chemical composition of the product (see p. 47), and the price at which Natural cement is sold does not warrant great refinement.

Process of Manufacture of Natural Cement. There is less variety in the methods employed for producing Natural cement than for Portland.

**Engineering Record*, Dec. 17, 1898, p. 47, and personal correspondence.

In a typical plant, the stones, of about the size that would be required for a large crusher, are brought from the quarry in carts or cars and dumped directly into the top of the kilns, which are of boiler iron lined with firebrick. They have no chimneys, but are open at the top and of the same size throughout. Thick layers of stone are alternated with thin layers of pea coal. The clinker is drawn out at the bottom as it is burned.

In the older plants the burned clinker is crushed and then ground between mill stones, while the newer mills use grinding machinery similar to that in Portland cement plants. When burnt, Natural cement rock is more readily powdered than Portland cement clinker.

PUZZOLAN CEMENT MANUFACTURE*

Puzzolan cement is made in the United States from blast furnace slag mixed with slaked lime. In Europe, natural puzzolanic materials have been employed.

The process of manufacture consists essentially of cooling the slag, mixing it with slaked lime, and grinding to a very fine powder.

Slag for Puzzolan Cement. For making pig iron a blast furnace is charged with a mixture of iron ores, fluxes (consisting of limestone, either calcite or dolomite) and fuel, in the proper chemical proportions to produce, after reduction by heat, products of definite chemical composition. These resulting products are pig iron and slag. Any one unacquainted with metallurgy naturally thinks of blast furnace slag as a compound of iron. This is incorrect, as iron forms only a very small impurity.

All slags are not suitable for Puzzolan cement, as they ordinarily contain too high a percentage of magnesia and are often too high in alumina. The specifications for slag used in the manufacture of Steel Portland cement are as follows:†

Slag must analyze within the following limits:

	Per cent.
Silica plus alumina, not over	49
Alumina	13 to 16
Magnesia, under	4

Slag must be made in a hot furnace and must be of light gray color.

Slag must be thoroughly disintegrated by the action of a large stream of cold water directed against it with considerable force. This contact should be made as near the furnace as is possible."

Mr. E. Candlot says‡ "The slag must be basic; according to Mr. Tet-

*An investigation of the manufacture and properties of Puzzolan cement is given in Report of Board of Engineers, U. S. A., 1900, on Steel Portland cement.

†Report of Board of Engineers, U. S. A., 1900, on Steel Portland Cement.

‡Ciments et Chaux Hydrauliques, 1898, p. 157.

majer, when the ratio $\frac{CaO}{SiO_2}$ falls below unity the slag is useless; the ratio of alumina to silica must be between 0.45 and 0.50. According to Mr. Prost, the composition of slags habitually used in the manufacture of Puzzolan cements must be nearly represented by the formula 2 SiO_2, Al_2O_3, 3 CaO."

Mr. E. C. Eckel* gives the following analyses of slag and slag cement:

Analyses of Slags in Actual Use and Composition of Slag Cements

CONSTITUENT.	SLAG: Choindez, Switzerland.	SLAG: Saulnes, France.	SLAG: Chicago, Ill.	CEMENT: Choindez, Switzerland.	CEMENT: Saulnes, France.	CEMENT: Chicago, Ill.
SiO_2	26.24	31.50	32.20	19.5	22.45	28.95
Al_2O_3	24.74	16.62	15.50	17.5	13.95	11.40
FeO	0.49	0.62			3.30	0.54
CaO	46.83	46.10	48.14	54.0	51.10	50.29
MgO	0.88		2.27		1.35	2.96
CaS	0.59					
$CaSO_4$	0.32					
S						1.37
SO_3					0.35	
Loss on ignition					7.50	3.39
$\frac{CaO}{SiO_2}$	1.78	1.46	1.49			
$\frac{Al_2O_3}{SiO_2}$	0.93	0.52	0.48			

Process of Manufacture of Puzzolan Cement. No kilns are required except for burning the lime. Molten slag as it flows from the blast furnace is granulated by coming in contact with a stream of cold water. This renders the product more strongly hydraulic, and most of the sulphur is removed as it strikes the water. As sent to the cement plant, it usually contains from 30% to 40% of water, and the first operation is to pass it through a dryer. The dried slag may or may not have a preliminary grinding before adding the slaked lime.

The lime is produced by burning a pure limestone, and then slaking it with water to which has been added a small percentage of caustic soda or other similar material, to make the resulting cement quicker setting. After drying, the slaked lime is mixed with the slag and ground in ball mills and tube mills, or in other forms of fine grinding machinery, and is ready for packing in bags or barrels for shipment.

*Mineral Resources of the United States, 1901.

CHAPTER XXIX

REFERENCES TO CONCRETE LITERATURE

While this chapter is not a complete bibliography of concrete literature, it presents a comprehensive list of valuable books and articles relating to the subject.

Under General References the names of authors are arranged alphabetically. The various subject headings under Subject References are also arranged alphabetically, and the references are printed in order of dates, the latest first. Articles are usually described by their subject-matter instead of giving their titles verbatim. In the case of similar articles printed in two or more periodicals, preference is generally given to the one bearing the earlier date. For references to this treatise see the Index.

ABBREVIATIONS

The following abbreviations (most of which correspond to those adopted by the Engineering Index) are employed:

Ann. de Ponts et Chauss.—Annales des Ponts et Chaussées. m. Paris.
Arch. Rec.—Architectural Record. New York.
Beton u. Eisen.—Beton und Eisen. Vienna.
Can. Eng.—Canadian Engineer. Montreal, Canada.
Cement and Eng. News.—Cement and Engineering News. Chicago.
Comptes Rendus—Comptes Rendus de l'Académie des Sciences. Paris.
Con. Eng.—Concrete Engineering. Cleveland, Ohio.
Deutsche Bau.—Deutsche Bauzeitung. Berlin.
Eng. Contr.—Engineering Contracting. New York.
Eng. Mag. — Engineering Magazine. New York & London.
Eng. News. — Engineering News. New York.
Eng. Rec. — Engineering Record. New York.
Gen. Civ. — Génie Civil. Paris.
Ins. Eng. — Insurance Engineering. Boston.
Int. Eng. Cong. — International Engineering Congress, St. Louis, 1904.
Jour. Am. Chem. Soc. — Journal American Chemical Society. Easton, Pa.
Jour. Assn. Eng. Socs. — Journal of the Association of Engineering Societies, Philadelphia.
Jour. Fr. Inst. — Journal Franklin Institute. Philadelphia.
Jour. W. Soc. Engs. — Journal of the Western Society of Engineers, Chicago.
Munic. Engng. — Municipal Engineering. Indianapolis.
Oest. Monatschr. f. d. Oeff. Baudienst. — Oesterreichische Monatsschrift für den Oeffentlichen Baudienst. Vienna.