

## II.

*(Paper No. 2385.)***“The Inspection of Portland Cement for Public Works.”**

By ALFRED EDWARD CAREY, M. Inst. C.E.

IN this Paper it is proposed to deal with the measures which appear desirable for the inspection of Portland cement for Public Works, in relation to its manufacture and use.

The Papers on cement by the late Mr. John Grant,<sup>1</sup> and the discussions to which they gave rise, led to the general use of a system of tensile tests; and the subsequent development of the manufacture, and of the present system of testing cement, are described in several Papers in the Minutes of the Institution.

## MANUFACTURE.

Some supervision of the manufacture is almost essential in order to judge of the quality of Portland cement; and in the specification of any contract in which it forms a vital constituent, power should be reserved to the engineer, or his agent, to visit the works of the maker at discretion. This is especially desirable in cases in which it is only possible to institute short-term tests. The points of greatest importance are: uniformity of raw materials; completeness of the mechanical blending; the proportion of carbonate of lime; thoroughness of wet grinding; the burning; the flouring; the aeration; and the packing of the finished cement.

*Uniformity of Raw Materials.*—The variation in the amount of coarse sand present in the clay (*i.e.*, of grains of free silica too large to enter into combination at the clinkering temperature) is of importance, as it is practically a passive adulterant. Its proportion may be tested by an elutriator, or Shone's apparatus.

The Author finds that gault clay contains an average of about 3 per cent. of sand, and the Gillingham mud about 7·9 per cent. The percentage of uncombined silica should not exceed 1 per cent.; but many cements now in the market contain 2 per cent. or more.

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<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. xxv. p. 66, and vol. xxxii. p. 266.

The analyses of two samples of gault clay, from Kent and Sussex respectively, are as follows :—

Constituents.	Kent.	Sussex.
Water of combination and organic matter.	4·09	3·43
Oxide of iron . . . . .	4·03	4·33
Alumina . . . . .	12·69	13·13
Carbonate of lime . . . . .	21·97	
Lime . . . . .	..	10·58
Carbonic acid, alkalies, &c. . . . .	..	11·73
Magnesia and alkalies . . . . .	0·88	
Insoluble siliceous matter . . . . .	56·34	56·80
	100·00	100·00

The essential constituents of cement are lime, silica, and alumina (generally in combination with iron), the other bodies, when not present in excess, acting negatively.<sup>1</sup> The substances to which the hydraulic properties are due are the silica and alumina (with iron); and the highest standard of quality is probably attained, when 6 parts of lime, 2 of silica, and 1 of alumina with iron, are

present in combination, the ratio being  $\frac{\text{Lime}}{\text{Hydraulic Factors}} = 2$ .

Oxide of iron in the clay, in any considerable proportion, affects the colour of the cement; and gypsum and iron pyrites reduce the rapidity of its setting, besides causing it to attain its maximum tensile strength more rapidly. Gypsum, if present in any quantity, affects disastrously the permanence of the strength of cement, and for this reason great caution is necessary in using gault clay. An excessive proportion of clay increases the rapidity of the setting, while an excess of lime retards it. Slow-setting qualities render a cement, therefore, unsafe for use, unless due to age or thorough clinking.

White and grey chalk, as well as the many varieties of limestone, are used for the manufacture of Portland cement. Grey chalk is more easily washed than the white; but, in using it, greater vigilance is necessary with the calcimeter, owing to its varying chemical composition. Another source of lime has been proposed, namely, the vat waste, in connection with the Chance sulphur recovery process, in which the precipitate is in the finest possible state of

<sup>1</sup> For analyses of cement and raw materials see Appendix I.

mechanical subdivision. Cement made from magnesian limestones, or from those in which the salts of magnesia are present in any considerable proportion, are often highly dangerous for reasons stated hereafter.

*Completeness of the Mechanical Blending of the Raw Material.*—The Author considers that the best shape for the washmill tank is octagonal. The mill should be driven at a high velocity (say 22 revolutions per minute), as the materials are thus combined with a minimum of water; 25 per cent. of water being the best result obtained to the Author's knowledge. The system of settling backs has generally given place to the Goreham process. The former, apart from the length of time, and the space it necessitates, allows the materials to settle in strata of different density. It is claimed by some makers that this is an advantage; as, when sandy clay is used, it enables the coarse sand to be dug out and removed from the slurry. In laying out new works, however, the Goreham system is now generally adopted. Most makers advocate weighing the raw materials into the washmill; but this, owing to the varying proportions of moisture they contain, is little real check; and careful calcimeter, or other chemical tests, taken periodically, are essential. The washmill used is of a type similar to those employed in brickworks, but for so thick a material as cement slurry, the power it absorbs is excessive. At the Reliance Portland Cement Works, Rochester, the Author has recently introduced with success an edge-runner mill for this purpose.

Factories are now in operation for utilizing a deposit of chalk marl, near Cambridge, for the manufacture of Portland cement. The conditions are unusually favourable, the marl being remarkably regular in chemical composition, and blended physically to perfection; so that Portland cement clinker, of a high class, can be produced by burning the material, to a large extent, in a raw state, as dug.

*Proportion of Carbonate of Lime.*—The greatest care is necessary in keeping the composition of the wash constant; and calcimeter tests should be made at intervals of a few hours. It is desirable that engineers, in specifying the quality of Portland cement, should require evidence of the proportion of carbonate of lime contained in the slurry. Probably 76 per cent. will be found to give the best results in most cases; but the amount of coarse sand, or intractable silica in the clay, has to be considered in this connection. There has been a reaction of late against cements which develop a high tensile strength quickly. Probably, con-

sidering the analyses of the raw materials commonly used in manufacture, and the ordinary systems of burning, a percentage of less than 72 per cent. would, in the majority of cases, result in a permanently weak cement. No hard and fast rule is possible, for to produce analogous results, the proportions of lime and alumina should vary inversely; and, subject to the above reservations, the clinker should result in a chemical compound of definite constitution within narrow limits.

*Thoroughness of Wet Grinding.*—The wet grinding is one of the most critical operations in the manufacture of cement, and neglect at this stage is fatal to good results. All slurry, as it flows from the wet stones, should be ground so fine, that after the moisture has been expelled it may leave a residue not exceeding 8 per cent. on a 22,500 mesh; but it is difficult, when white chalk is used, and there is much flint, to obtain so good a result. The usual practice is for the wet miller, at intervals, to wash a handful of the wet slurry through a sieve of 1,600 or 2,500 meshes per square inch, testing it constantly for its creaminess, or absence of grit, by touch. This system, however, gives imperfect results. In clinker produced from badly ground slurry, minute particles of caustic lime are visible; and after dry grinding, these become hydrated, and slowly absorb carbonic acid from the air, the absorption with well-burnt cement, spread in thin layers, being about 1 per cent. in the first four days. Even if sufficiently hydrated before use not to blow in the work, the caustic lime is inert and soluble, and in sea-water, it sets up a precipitation of magnesia.

*Burning.*—Chemically, the first effect in burning is to expel the carbonic acid from the carbonate of lime, producing oxide of calcium, or caustic lime. This change takes place at 440° Centigrade (824° Fahrenheit); and the silica and lime gradually unite to form silicate of lime, until a temperature of 700° Centigrade (1,292° Fahrenheit) is reached, when the alumina comes into action, uniting with the silicate of lime to form a body of complex constitution. The temperature rises to about 1,600° Centigrade (2,912° Fahrenheit), but this degree of heat should be kept up for a short time only, otherwise a glassy, and comparatively inert substance is formed, instead of a body in a condition of potential chemical activity. Although chemically identical in composition, the clinker produced with prolonged heat has a comparatively permanent crystalline structure. The iron which, in contact with lime, fuses at a lower temperature than the other bodies in combination, forms a film upon the clinker of a bluish black colour; and the greenish bloom on the surface of well-burnt clinker is attributed

by Dr. Michaëlis<sup>1</sup> to the trace of manganese present in the clay. This probably exists in combination with ferric oxide; and the colour described is a good index of well-burnt clinker. The combinations of lime, silica, and alumina, being of a whitish colour, and covered with coloured substances, underburnt clinker will have a greenish grey tint, overburnt clinker a dull bluish black, unless an excess of sulphur is present in the clay or the fuel, when it will be mottled with red or yellow. About 13 per cent. of alumina is probably the maximum desirable to ensure the best results, as with more than this, in producing the more complex alumina compounds, the simpler silica compounds are overburnt, and rendered inert when hydrated in gauging.

In modern cement works, closed kilns, of which a large variety of types are in use, are generally adopted; and in these, the waste heat from the burning is utilized for drying the slip upon adjoining floors. The Author proposes to use the term "metamorphism" in classifying the changes produced by the partial fusion which takes place in the burning of cement. This action probably bears considerable analogy to the processes of transformation, which occur in the production of igneous rock masses. That lime acts as a flux is shown by variations in the proportions of the raw materials affecting the quantity of fuel necessary to bring about the desired degree of metamorphosis. Under similar conditions, the free lime in the clinker is inversely proportionate to the degree of heat attained. Spontaneous pulverization may often be observed in cement clinker, a large mass rapidly flying to pieces, and becoming merely a heap of powder, intense heat being simultaneously disengaged. This result has been shown by Mr. H. Le Chatelier,<sup>2</sup> to be due solely to the presence of the bicalcic silicate,  $\text{SiO}_2 \cdot 2\text{CaO}$ . The powder so produced is devoid of cementitious properties.

The systems of burning generally in use appear eminently unscientific, as large masses of hard clinker are produced, the crushing and grinding of which are costly processes, involving great wear and tear. Moreover, if the core of these masses is properly burnt, the outside must be overburnt, and *vice versa*. Specifications vary widely in their requirements as to the burning. One specification compels the clinker to be broken into pieces which will pass through a 4-inch ring, and requires that all the under-burnt and over-burnt portions shall be carefully picked out by daylight.

<sup>1</sup> Das Wesen und der Erhärtungs-Process des Portland-Cementes.

<sup>2</sup> Recherches expérimentales sur la Constitution des Mortiers Hydrauliques, p. 53.

The picking out of the "yellows" and "pinks," or under-burnt clinker, is more important than that of the "glassy," or over-burnt, the former causing disintegration, while the latter is merely a passive adulterant. The processes of Mr. W. Joy (Messrs. Peters Bros.), and Mr. F. Ransome, Assoc. Inst. C.E., have for their object the production of clinker in a state of finer subdivision, and more uniformly burnt, than that hitherto obtained. In the latest development of the Ransome system, the dried slip is reduced to a fine powder, in a mortar mill or otherwise. It is then fed into a hopper communicating with an inclined iron cylinder lined with firebricks, several courses of which are deeper than the rest of the lining, thus forming longitudinal ledges. The cylinder is made to revolve, and the powdered slip, in its revolution, is thus alternately lifted and dropped until it leaves the lower end. At this end, a flue is led into the cylinder, and is in connection with a gas generator. The combustion of the gas in the cylinder roasts the fine particles of powder, which are delivered in the form of cement clinker in a spongy condition, and ready for the dry grinding. This system was tried, but subsequently abandoned, at the works of Messrs. Gibbs and Co., Grays, and also at the Arlesey Works, Bedfordshire. Mr. W. Stokes has introduced an improvement upon this process, which is being put into operation at the Arlesey Company's works. In Joy's process, a wet mixture of slip and fuel is fed through an eye at the side of a domed kiln, the upper surface of the contents of which is covered with slip, thrown by hand to any point in the crust at which flames may burst through. Dried slip without fuel is fed into the kiln in increasing proportions as the burning off progresses. The high quality of the cement made by this process, the Author considers to be due to the conversion of carbon dioxide into carbonic oxide, no vapour escaping from the kiln, and a blue lambent flame playing over the surface of the burning mass. The flame of carbonic oxide, burning in air, is estimated to have a temperature of about 2000° Centigrade (3,632° Fahrenheit).<sup>1</sup> An intense heat, of short duration only, is thus applied over the crust of the burning mass; whereas long-continued heat tends to deteriorate the quality of cement clinker. In this case, the clinker comes away in honey-combed masses which have been burnt in detail. A more friable and uniformly burnt clinker is thus produced, which requires less power in grinding than ordinary clinker, the wear of the kilns by Joy's process being also much reduced. A somewhat

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<sup>1</sup> C. L. Bloxam's Chemistry, 1886, p. 89.

similar result is aimed at in the Dietsch kiln, which is in use on the Tyne, and near Cambridge.

One of the most valuable data in connection with the burning, is the specific gravity of the cement, as was pointed out by Sir Frederick Bramwell, Past Pres. Inst. C.E., in 1865.<sup>1</sup> The apparatus described by him, is similar to that now known as Dr. Schumann's,<sup>2</sup> in which the specific gravity is found from the displacement of turpentine in a graduated glass tube, by the insertion of a given weight of cement. Care should be taken that the moisture and carbonic acid are expelled from the cement before using the instrument, as it has been demonstrated that, with age and exposure, the specific gravity is materially decreased. A result much lower than 3·1, after drying for fifteen minutes in a desiccator, may generally be taken as an indication that the clinker is underburnt. The specific gravity of a given cement is the same whether it is finely or coarsely ground. A minimum of 3·0 was fixed by the Munich Congress of 1884; and the standard of 3·1 has been objected to as excessive. A low specific gravity combined with a high tensile strength at seven days, are conditions pointing to an unreliable cement, which will rapidly deteriorate. The test of the weight per bushel should be abandoned, and the specific gravity substituted, the former being so inexact as to be practically valueless.

*Flouring.*—There is no condition in cement-making where the requirements of the users have been more progressive than that of fineness of grinding; and the specification of a residue of 10 per cent. on a 50 × 50 mesh is fast becoming obsolete as a standard test. The residue, even from a mesh of 32,257 divisions per square inch, possesses practically no cementitious value when gauged with sand; and in cement, it is the "flour," or impalpable powder, which is the really effective part, the "nibs," or coarse residue, forming an adulterant equivalent to the admixture of a similar proportion of sand. With finely ground cements there is, moreover, less risk from the expansion of the caustic lime from hydration.

The increase in value of a cement due to fineness of grinding is shown more clearly by sand tests than by neat tests, each minute particle requiring to be painted over by a thin coating of cement

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<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. xxv. p. 137.

<sup>2</sup> Minutes of Transactions of the Verein Deutscher Cement-Fabrikanten, Feb. 1883, p. 47. [See also "Elements of Agricultural Chemistry," by Sir Humphry Davy, p. 176.—Sec. Inst. C.E.]

in gauging; and the more finely ground it is, the greater the surface which is thus covered. The Author is of opinion that in specifications, it would be far better to allow a large percentage of residue on an exceedingly fine mesh than a small residue on a coarser mesh. The practice of sieving on works does not necessarily conduce to an improvement in quality, as the miller, trusting to the sieves to reject any coarse particles, may set his stones so as to produce a cement of coarser average than would be possible if he was grinding without sieves. In the one case, the grind would have to be maintained at the maximum, in the other case, at the mean of the required degree of fineness. The following results demonstrate the value of fine grinding. The tests were made with one part of cement, of specific gravity 3.125, and three of standard sand gauged with 10 per cent. of fresh water. The temperature of the air and of the cement was 46° Fahrenheit, and the results were obtained at twenty-eight days, being the average of 6 briquettes in each case.

Cement.		Tensile Strain per Square Inch Section.
		Lbs.
As ground, <i>i.e.</i> , 9 per cent. on 50 × 50 mesh . . . .		220
With residue on 50 × 50 mesh removed. . . . .		304
With residue on 75 × 75 mesh removed. . . . .		311
With residue on 32,257 mesh removed . . . . .		360

Dr. Michaëlis<sup>1</sup> has proved the inertness of the residue upon a sieve of 5,000 meshes per square centimetre (32,257 per square inch) by sand tests made, (1) with a given volume of cement as ground, (2) with the smaller volume of cement due to sifting out the residue on this mesh. The strength of the tests was not materially reduced by the loss of the coarser particles, which were therefore of no cementitious value. This has been further proved by the Author, by gauging into briquettes the residue left upon this mesh, when a feebly cohering mass results.

Cement, as it comes away from ordinary millstones, has a temperature of 150° to 160° Fahrenheit; and in grinding cement of a specific gravity of about 3.1, and of a fineness of about 8 per cent. on a 2,500 mesh, an ordinary pair of 4½ feet millstones, driven at 140 revolutions per minute, produce 25 to 32 cwts. per hour, and absorb 35 to 40 HP. Edge-runner mills have been tried at various times, with doubtful results as to quality, the absence of the shearing action of millstones appearing to produce particles

<sup>1</sup> Zur Werthstellung der Zemente. (Deutsche Bauzeitung No. 101, 1876.)



which, not being subdivided along the lines of cleavage, fail to bond in gauging. A comparative trial made by the Author, of a new edge-runner mill, with the same degree of fineness, gave results superior in tensile strength to that ground in the ordinary way. The net power absorbed per ton per hour, in grinding, was 14·96 HP.; and the cement left the mill at a temperature of 75° to 77° Fahrenheit.

*Aeration.*—With the imperfect systems of burning and grinding generally in use, it is essential that cement should be well aerated or “purged” before use, in order to air-slake any caustic lime it may contain, the high temperature at which it is delivered from millstones also necessitating exposure in order to cool it. The more finely ground a cement is, the more rapidly air-slaking is effected; and probably in a few years the improvements now being introduced in the manufacture will render aeration unnecessary, and cement will be produced in a fit state for immediate use. The quantity of cement stored should be not less than ten weeks’ production; and the distributing worms or belts should be arranged so as to deliver the cement, as it comes away from the dry mill, to any part of the store. By this means the expensive and unpleasant operation of turning and spreading it by hand, may be to a large extent avoided. In accepting tenders for cement, the capacity of the store at the factory in question is a matter worthy of careful consideration; as, in times of pressure, makers will often be tempted to load up imperfectly aerated cement. A proper arrangement of bins is also desirable, as it assists an inspector in making sure that the cement which he has sampled is really consigned. A little observation will enable him to estimate, from the rate at which the compartments allotted to his order are being emptied, whether any attempt is being made to pass off other material than that which he has sampled.

*Packing.*—Attempts have been made from time to time to improve the packing of cement for transport or shipment; but sacks and barrels still hold the field. The size of the former, for English use, is equal to 10 or 11 to the ton; for French export, 50 kilogrammes (about 1 cwt.) each. Water-proof sacks have been used for export purposes, but have never come into common use. The cost of 400-lb. machine-made casks per ton of cement varies, with the number of hoops and bars, from 7s. to 7s. 6d. With hand-made casks, the cost is from 9s. to 10s. per ton. In order to utilize a larger proportion of stores, both systems are often simultaneously adopted, giving an average increase of say 8s. 6d. per ton to the cost of cement for export purposes. The weight of

casks of this size is about 24 lbs. each, or 144 lbs. per ton of cement; and the rates of insurance of cement, except for total loss, are practically prohibitive.

As well-burnt cement clinker, from which the dust is removed, is little injured by exposure to any reasonable degree of damp, it might, in many cases of foreign works, be wise to erect grinding plant on the spot, and export cement clinker. An inspector should superintend the consignment up to its delivery on board, especially when it is loaded in sacks and lightered alongside the vessel.

#### TESTING.

The types of machine for tensile testing are various, and too well known to need description; and the best shape of briquette was so carefully investigated by the late Mr. J. Grant, that this point may be considered practically determined. The early briquettes were almost universally of  $1\frac{1}{2}$  inch  $\times$   $1\frac{1}{2}$  inch section; but this size is rapidly being given up in favour of the 1 inch  $\times$  1 inch section. The weight of cement in a briquette of  $1\frac{1}{2}$  inch  $\times$   $1\frac{1}{2}$  inch section is about 2 lbs., too large a quantity to manipulate satisfactorily, especially when the material is quick-setting. The similar weight for a 1 inch  $\times$  1 inch briquette is about 5 ounces; and two briquettes, or with slow-setting cement three briquettes, are as many as should be gauged at one time. The method of clamping the moulds should be such as not to strain or jar the briquettes in getting them out. The proportion of water should be taken by weight rather than by volume. The Author considers that a handy machine is wanted to test briquettes of  $\frac{1}{2}$  inch  $\times$   $\frac{1}{2}$  inch section, so that an inspector may be enabled to gauge up a series of briquettes at the maker's factory more rapidly than is possible with the present machines; and this would be especially serviceable in enabling him to form a judgment in short-term tests.

The best calcimeter is the "Dietrich" apparatus, in which the carbonic acid given off, in treating a given quantity of slurry or cement with a fixed weight of hydrochloric acid, is measured by displacement of a column of mercury or distilled water. The weight of material, which has to be taken with great accuracy to the tenth of a milligram, is dependent on the temperature and state of the barometer; and this weight is taken from the Tables supplied, which have to be calculated for each apparatus. A certain quantity of carbonic acid is absorbed by the hydrochloric acid, and the correction for this is found from a second Table, and

added to the amount registered on the measuring tube of the apparatus. The moisture in the material to be tested should be expelled in a water oven at a temperature of 212° Fahrenheit, and it should be then dried in a desiccator, as these bodies are strongly hygroscopic.

The conditions of a standard test in compression are as yet undefined; and some difference of opinion exists as to the desirability of instituting such tests. Dr. Michaëlis' hydraulic compression testing machines are probably unrivalled in range and accuracy. For weak bodies, such as mortar mixtures with much sand, &c., the size of the blocks used is 100 square centimetres (about 16 square inches), and for pure cement and rich mixtures, test blocks of 50 square centimetres (about 8 square inches). A pressure of 69,000 kilos (about 68 tons) may be exerted with this press, the weight of which is about 18 cwt. The cost of reliable compression testing machines is too great to admit of their general adoption; but the system of employing independent inspection of cement is likely to be more and more widely followed. It has been urged that the Institution of Civil Engineers should recommend a series of standard regulations as to the testing of cement, similar to those adopted by foreign governments and public bodies. Such a step, however, might tend to check the progressive improvement in quality, which has been so marked in spite of the want of uniformity in engineers' specifications. Cement makers are often asked to fulfil impossible conditions, and would welcome the establishment of a normal standard of quality. Had such a standard been formulated ten years ago, its effect would, in all probability, have been retrograde, tending to the production of cement of a lower average quality than has been evolved by the present system. The German rules fixed the 3 to 1 sand test at 28 days as follows:—

In 1877 at 113·8 lbs. per square inch.

In 1878 at 142·2 lbs.   "   "   "

In 1887 at 222·5 lbs.   "   "   "

The Prussian Ministry for Commerce, Manufacture, and Public Works has drawn up a standard specification, which is also accepted by the Berlin Society of Architects, the Society of Contractors, &c.<sup>1</sup> The specification adopted for the Boulogne Harbour Works<sup>2</sup> is approximately the standard for government

<sup>1</sup> A translation of this specification has been placed in the Library of the Institution.

<sup>2</sup> Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 457.

works in France. The Austrian Association of Engineers and Architects have a code of regulations; and normal standards have been formulated in Sweden, Switzerland, and Russia. In the United States, a committee of the American Society of Civil Engineers<sup>1</sup> reported, in 1885, in favour of a uniform system of testing, on lines devised by them. The irregularity in the testing arrangements in the United States had previously been much complained of by English manufacturers and others, and the conditions of supply were admittedly unsatisfactory.<sup>2</sup> At the present time, there is no uniformity of practice amongst engineers and users of cement in the United States. If it was attempted to apply the foreign specifications quoted to English public works, they would probably remain practically a dead letter. In framing a specification for Portland cement, the essential point is to give wide discretionary powers to the engineer, or his agent, avoiding unnecessarily troublesome conditions. The Author submits a standard specification in Appendix II, which it might be necessary to supplement when the cement is to be used under exceptional circumstances. Compression tests will probably be required in the near future.

In some specifications, the seven days' test is taken at seven days after gauging; in others, at seven days after immersion. The former is preferable, as this obviates the date of breaking sometimes falling on a Sunday, in which case the briquettes are usually broken at eight, instead of seven days. Some specifications state the proportions of the raw materials to be used in manufacture; but this is an undue interference with the function of the cement maker, and is of doubtful utility. It is far more important to have evidence of the regularity of the wash, from which the degree of care and accuracy with which the manufacture is being carried on may be inferred. In specifications in which cement is to be specially quick-setting, as when required for use in a plastic state in a tideway, or in broken water, the result of tests by the Vicat needle should be required; but such vague expressions as "finely ground," "quick-setting," and "slow-setting," should be avoided in specifications. It is also undesirable to state definitely the proportion of water to be used in gauging, as this, if rigidly adhered to, may mislead; but a record of it is essential to a due knowledge of the value, for constructive purposes, of any particular sample of cement. In gauging up briquettes, the best results are

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<sup>1</sup> Transactions of the American Society of Civil Engineers, vol. xiv. Nov. 1885.

<sup>2</sup> *Ibid.*, vol. vi. p. 312, Dec. 1877.

obtained with those in which a smooth, viscous, gelatinous body rises to the surface; and this quickly crystallizes into a homogeneous skin. If an excess of water is used, this face may be washed away in gauging; and, in this event, or should it be trowelled away, the breaking strains are always lower than fair maximum results. This superficial coating probably consists of the alumina silicates in solution, the nearest analogy being the hard skin produced in vitrification, or on the surface of pottery, &c. The manipulation of a cement enables an experienced gauger to form an opinion of its qualities; and any mechanical substitute for trowelling up briquettes is of dubious advantage. An ingenious contrivance with this object is the Arnold mould, in which a given weight of cement is placed dry in a mould, and, after compression in a screw press, is placed in a tray of water from which it absorbs the required proportion. One objection to this apparatus is that it is more favourable to a light than a heavy cement, as, owing to its greater volume, the former is more compressed than the latter. A quick-setting cement is, moreover, at a disadvantage, as the immersed face becomes set before the water has penetrated equally to all parts of the briquette; and a third objection is that, as the briquettes are dealt with in a series at one operation, the weight of water absorbed by each cannot be accurately measured. Results obtained by this apparatus should not be compared with those made in the ordinary way.

#### ADULTERATION OF CEMENT.

The adulteration of cement and the means of detecting it were investigated by Messrs. R. & W. Fresenius, on behalf of the Society of German Cement Manufacturers.<sup>1</sup> Probably in this country no systematic adulteration of cement is practised; but it was stated in the report above mentioned, that in Germany, bodies were frequently mixed with Portland cement so closely resembling it in chemical composition that even a quantitative analysis was not a certain guide. The behaviour of twelve samples of Portland cement from England, France, and Germany was compared with that of three kinds of hydraulic lime, three kinds of slag meal, and two kinds of milled slag, the chief adulterants expected. Messrs. R. & W. Fresenius found the principal characteristics of a pure Portland cement to be that it should have a specific gravity of 3.125 (certainly not less than 3.1), that the loss on

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. lxxix. p. 377.

ignition should be between 0·34 and 2·59 per cent., that 3 grammes of cement should absorb from 0 to 1·8 milligram of carbonic acid, that the alkaline substances extracted by water from 1 gramme of cement should correspond to from 8 to 12·5 cubic centimetres of decinormal acid, and that one gramme of cement, treated with normal acid, should neutralize between 18·8 and 21·67 cubic centimetres of it.

# USES.

The next few years are likely to show, not only an increase in the scope and boldness of the applications of concrete to engineering works, but also its adaptation to many minor purposes in lieu of cast-iron and timber. A trial was recently carried out by the Author, of the strength of telegraph poles of concrete and iron in combination, made under the system patented by Mr. D. Wilson, of Tilbury, Essex, with the results given below.<sup>1</sup>

The advantages of substituting such a material as concrete for iron and wood, in many situations, are that it does not decay or corrode; it cannot be attacked by the teredo, or the white ant; it should not be subject to expansion or contraction; its strength, especially in damp localities, should become greater with age; and in many cases it can be cheaply cast on the spot, the cement being the only material to be transported. A telegraph pole of this type collapses gradually when subjected to an extreme strain, and is thus less likely to be a dangerous obstruction on a highway or railway than wooden poles are when they snap or are uprooted. The disadvantages of concrete, as compared with wooden poles, are its greater weight, and the necessity of more care in transport to prevent injury.

Weight Applied. lbs.	Deflection. Inches.
240 . . . . .	1½
480 . . . . .	3
600 . . . . .	4
840 . . . . .	5½
1080 . . . . .	7½
1320 . . . . .	9½
1440 . . . . .	11½
1600 Pole slowly deflected, but did not collapse.	

Weight of 31-foot pole about 840 lbs. Diameter at the butt, 7¼ inches, and at the top, 4 inches. The pole was fixed horizontally, 6 feet of the butt being wedged into a chalk bank, and a support placed 15½ feet from the bank. The weights were applied 6 feet beyond the prop, or 3½ feet from the end of the pole.

In order to ascertain the power of Portland cement to resist hydrostatic pressure, a set of experiments were, on the Author's suggestion, undertaken by Mr. Joseph Cash, M. Inst. C.E., at the Brighton Gasworks, the results of which are given in Appendix III.

There is great diversity in the hand-mixing of concrete, both as to the volume of water used, and the time over which the operation is spread; and these conditions directly affect the strength and permanence of the resulting work. The Author obtained the best results by using about 22 gallons of water per cubic yard of raw materials, equal to about 1 part by volume to  $7\frac{1}{2}$  parts, less than this quantity not securing that glassy film upon the surface of finished work which is so desirable, and more than this washing away some portion of the soluble alumina silicates which are the active ingredients in concretion. That a sufficiency of water in gauging concrete is advantageous, will be seen from the following results; although, in gauging briquettes for tensile testing, the smallest proportion of water compatible with thorough damping is undoubtedly the best.

#### CRUSHING STRAINS AT TWENTY-EIGHT DAYS.

Size of Blocks.	Conditions.	Crushing Strains per square inch.
Cubic Inches.		lbs.
$3\frac{1}{16}$ . . .	<div> <div> 3 normal sand to 1 cement, with  20 per cent. fresh water . . . </div> <div> 3 normal sand to 1 cement, with  10 per cent. fresh water . . . </div> </div>	<div> 1679  1425 (average) </div>

The purity of the water is a matter of vital importance. On the Newhaven Harbour Works, the water used for the 100-ton foundation sack blocks was taken direct from the river; <sup>1</sup> and the Author found that it was essential to do the pumping on the flood tide, as on the ebb tide the river silt partially killed the cement. The percentage of earthy matter in many streams is so great <sup>2</sup> as to render their waters, in an unpurified state, unfit for use in concrete. To test this, six briquettes were gauged neat with 20 per cent. of distilled water, and cement of a specific gravity of 3.1, giving an average at seven days of 480 lbs. per square inch, and taking three hours to set. Six similar briquettes were gauged with a mixture of 49 parts by weight of distilled water, mixed with 1 part of Thames

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 102.

<sup>2</sup> Jukes' Manual of Geology, ed. by A. Geikie, pp. 423-4.

mud (equal to about  $\frac{1}{100}$ th mud by volume), which had been previously dried at 212° Fahrenheit, and powdered very fine. These briquettes took four hours to set, and gave an average at seven days of 411 lbs.

The effect of sulphuric acid on the strength of cement and concrete structures is demonstrated by the following results of tests, in which the same sample was used with fresh water, and with water containing sulphuric acid, each result being the average of six briquettes.

SULPHURIC ACID TESTS.

Proportions.	7 Days.	28 Days.
Neat cement, with 20 per cent. water . . . . .	550	—
"    with 19 per cent. water and 1 per cent. sulphuric acid . . . . .	151	272
1 cement and 1 normal sand, with 15 per cent. water . . . . .	335	415
"    "    with 15 per cent. of liquid, of which liquid 19 parts are water, and 1 part sulphuric acid	90	204
1 cement and 2 normal sand, with 15 per cent. water . . . . .	—	270
"    "    with 15 per cent. of liquid, of which liquid 19 parts are water, and 1 part sulphuric acid	50	108
1 cement and 3 normal sand, with 10 per cent. water . . . . .	—	200
"    "    with 10 per cent. of liquid, of which liquid 19 parts are water, and 1 per cent. sulphuric acid . . . . .	Nil.	Nil.

The temperature of the water used for concrete making also deserves consideration. The experiments given in Appendix IV show the effect of freezing briquettes at various stages, and for different lengths of time, and demonstrate that in cement gauged as it is in making briquettes, frost produces no deleterious effect, the setting properties being rendered dormant thereby, and the long-term tests being practically identical with those maintained at a higher temperature.

In concrete-making on public works, in which an excess of water is generally used, the effect of frost is to disintegrate the concrete by the expansion of the water in freezing; and measures to neutralize this effect have been investigated by the Russian and American authorities. It has been found that the addition of common salt to the water enables work to be carried on during hard frosts, the proportion of salt so employed even reaching 8 per cent. A temperature of 75° to 80° Fahrenheit was found by experiment to hasten the maturing of the cement, a result to be noted in relation to work in tropical waters.

Cement briquettes gauged in sea-water set more slowly than those gauged in fresh water, owing probably to physical rather



than chemical causes; and at seven days, they show higher results by about 15 per cent. Apparently salt-water briquettes attain their maximum at from six to nine months. The results in this respect of five years' testing at Newhaven Harbour<sup>1</sup> are corroborated by the figures, given in Appendix V, of long term tests of the cement of four English and four French makers of repute.

The molecular structure of Portland cement changes with age, its hardness and brittleness increasing, and its elasticity diminishing. There is a point, therefore, at which the cement begins to show a falling off in tensile strength, while the compression tests continue to improve. The gauging of cement with sea-water allows this result to be attained more speedily with the same cement. The setting with sea-water being slower, a more perfect crystalline structure is probably reached in a comparatively short time; so that the apparent deterioration, as evidenced by the falling off in tensile strains, is in reality rather a good sign.

There has been considerable discussion and much anxiety, during the last few years, as to the limits within which concrete may be safely employed, more especially on works in the sea. The influence of the salts of magnesia in affecting the life of a concrete structure is of special interest, having regard to the theory that, under certain conditions, the chemical transposition of lime from the cement, and magnesia from the sea-water, may produce disintegration. Two totally distinct issues have to be considered in dealing with this subject:—(1) The influence of magnesia as an ingredient in the manufacture of cement; and (2) the alleged deterioration of sound cements when subjected to the action of sea-water.

An excess of either lime or magnesia in a caustic form produces, when the cement is gauged, inconstancy of volume. Mr. Lechartier's Paper,<sup>2</sup> which is of great interest in relation to this question,<sup>3</sup> deals with a class of cements which he terms "*Ciments dits de Portland*." He describes a series of faults in concrete, which commenced to develop one year, or longer, after the construction of various works, and in which a slow and progressive chemical disintegration led eventually to its complete destruction. On analysis, the cements used in these structures were found to

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 113.

<sup>2</sup> Comptes Rendus de l'Académie des Sciences, vol. cii. p. 1223. The factory from which the cement in question was supplied has since been abandoned, owing to the numerous failures of the concrete, which were generally slowly developed.

<sup>3</sup> Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 162.

contain from 21·20 per cent. to 34·72 per cent. of magnesia, and only in one case as little as 12 per cent. No marketable Portland cement would show such an analysis, and therefore the results obtained are not comparable to those of ordinary practice. Mr. Lechartier attributed the failures to the hydration of the magnesia, accompanied by an increase in its volume, long after the setting of the cement, thus causing the destruction of works, the solidity of which appeared assured.<sup>1</sup> Analogous effects are not uncommon when an over-limed cement is used; but such results, when due to magnesia, are less rapid in their action. The Author had once to deal with an instance of this kind. A 6-inch flooring of mass concrete gauged with fresh water, was laid in a brick building, the walls of which were 18 inches thick. It was made with under-burnt and over-limed Portland cement, gauged with fresh water. An expansion of the flooring soon commenced, which, after forcing the walls out of line, caused the floor to assume a serrated form, and finally to disintegrate. In another instance a concrete structure in a tidal estuary, made with a natural cement containing an exceptionally large proportion of free lime, became fissured and disintegrated. On analysis the Author found that 14·7 per cent. of the lime had been dissolved, and 6·23 per cent. of magnesia had been deposited.

A wide difference of opinion exists as to the alleged deterioration of concrete in sea-water under certain conditions. The quantity of magnesium in sea-water, present as chloride and sulphate, amounts to 0·6 per cent. by weight. In a porous mass of concrete, a precipitation of the salts of magnesia takes place, some of the lime of the cement being at the same time dissolved. On one side it is held that these salts of magnesia, filling the pores and interstices of the concrete, subsequently undergo a change of volume, producing disintegration. On the other hand, it is asserted that these precipitates are absolutely inert, and do not in any way affect the strength of the concrete. Dr. Michaëlis, admitting the risk of disturbance of bond due to an excess of magnesium salts in the raw materials, has recommended that cement containing more than 5 per cent. of magnesia should be avoided.<sup>2</sup> He subsequently stated that disintegration of Portland cement by sea-water is not due to the magnesia present, but to

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 460.

<sup>2</sup> Das Wesen und der Erhärtungs-Process des Portland-Cementes, April 20, 1887.

the acids with which this body is combined. Portland cement usually contains from 1 to 3 per cent., and sometimes as much as 4 or 5 per cent. of magnesia. He considers it practically an adulterant, and that a correspondingly increased percentage of lime should be added to the raw materials, otherwise a low tensile strength may be anticipated. That cement with a high proportion of magnesia is of inconstant volume he thinks quite unproved; and cement tests, in which magnesia was present to the extent of 20 per cent., were under his observation for ten years, and showed no signs of flaw. He states that the weakness of many magnesian Portland cements is due to the mistake of regarding this body as actively useful, and of not adding a corresponding percentage of lime in manufacture. Tests made by him of correctly composed and properly burnt cement, containing from 18 to 20 per cent. of magnesia, show that no greater changes of volume occur in them than in normal cement with up to 3 per cent. of this substance. He does not consider it to be proved that a cement with 5 per cent. or more of magnesia, should on that account be rejected.<sup>1</sup>

The failure of a portion of the concrete walls of the graving dock at Aberdeen has led to considerable uneasiness with regard to concrete structures in the sea. Mr. P. J. Messent, M. Inst. C.E., reported that, in his opinion, failure was not to be traced to the use of cement of defective quality. It appears, also, that the practice of re-gauging or breaking up partially set concrete, and depositing it in this condition, which had been resorted to on other portions of the work, had not been applied to that part of the wall which gave way. From the porosity of the coating, which was composed of four parts of sand to one of cement, Mr. Messent deduced the theory of the deposition of magnesia from sea-water, its consequent expansion, and hence the disruption of the work.

Following up Mr. Messent's experiments, the Author experimented with one hundred and twenty briquettes, some made in neat cement, and others of one part of cement to one, two, three, and four of sand—an equal number of each kind. These were placed in a wooden cage, and secured at the level of low water of ordinary spring-tides at the pier-head at Newhaven Harbour forty-eight hours after gauging. They were thus exposed, not only to a constantly varying pressure due to the tidal movement, but also to the action of the waves at low-water. They were all

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<sup>1</sup> Wochenblatt für Baukunde, June 6, 1888.

carefully weighed and submerged before exposure, some for fourteen days, and others for twenty-eight days, three months, or six months. They were then surface dried by exposure in the air, and weighed afresh, with the results given in Appendix VI.

The average increase of weight from the time of immersion was as follows:—

Proportions.	14 Days.	28 Days.	3 Months.	6 Months.
	per cent.	per cent.	per cent.	per cent.
Neat . .	4·98	2·69	1·25	12·06
1 to 1 . .	4·53	2·28	0·38	9·57
1 to 2 . .	5·06	2·25	0·51	9·29
1 to 3 . .	6·16	2·25	2·51	10·20
1 to 4 . .	4·97	2·42	3·41	12·77

The breaking strains are also given in Appendix VI; and the briquettes did not show any signs of disintegration. The Author instituted another series of experiments in order to determine the effect upon the strength of partial gauging with sea-water, or of gauging with concentrated sea-water. The following Table gives the results obtained from an average of six briquettes of 1 inch section in each case, and shows that very little difference is traceable to these conditions. The whole of the briquettes were gauged neat with 20 per cent. of water, the temperature of the air ranging from 45° to 54° Fahrenheit, and that of the cement from 49° to 54° Fahrenheit.

TABLE SHOWING THE RESULTS OF USING SEA-WATER IN GAUGING: IN LBS.  
PER SQUARE INCH.

Water.	1 Month.	2 Months.	3 Months.	6 Months.	9 Months.	12 Months.
Fresh water . . .	525	555	750	900	949	678
$\frac{1}{2}$ Distilled water, and $\frac{1}{2}$ sea-water . . .	537	542	690	650	965	592
$\frac{1}{4}$ Distilled water, and $\frac{3}{4}$ sea-water . . .	542	550	620	750	950	575
Sea-water, 25 per cent. evaporated .	542 $\frac{1}{2}$	563	590	580	890	605
Sea-water, 50 per cent. evaporated .	541	540	800	850	970	495

The briquettes were not checked or cracked in any way. The cement used in both series of trials was sound, well burnt, and ground so as to leave a residue of about 10 per cent. on a 50  $\times$  50 mesh sieve.

The real point at issue is whether the salts of magnesia, which are admittedly deposited from the sea in porous concrete structures, are or are not inert. Magnesian limestones, when used for building purposes, are subject to weathering, especially in large cities where rain brings down sulphate of ammonia. This salt acts chemically upon the stone, producing carbonate of ammonia and sulphate of magnesia and lime, which latter are deposited as crystals in its pores, causing disintegration by their growth.<sup>1</sup> In situations in which ammonia may be brought into contact with concrete, it is desirable to use fresh water for gauging; and if analysis should show that an abnormal proportion of magnesia is present, the cement should, under such conditions, be rejected. Concrete, made of sound and well-burnt cement, varying from  $\frac{1}{4}$  to  $\frac{1}{12}$  part by volume, and gauged with sea-water, has been used for many existing structures in the sea, without visible deterioration for a long term of years. Those structures which are homogeneous, and are protected by a dense skin, are best adapted to resist the forces tending to disintegration. In the Author's opinion, no conclusive evidence has been adduced to prove that the precipitates from sea-water induce disintegration, even of fissured or porous concrete, when sound cement is used. Had such evidence been forthcoming, it would throw doubts on the durability of all such structures in the sea. In the Aberdeen experiments, it was demonstrated that free caustic lime had been washed out of the concrete, and magnesia as magnesium hydrate precipitated, with the formation of calcium chloride and sulphate. The analyses prove nothing beyond the fact that the caustic lime present was the cause of such precipitation, and that lime in this form is an unstable and soluble body. The inference that, by similar action long-continued, a dangerous portion of the lime may be dissolved out of the cement present in a concrete structure, is without proof. The precipitation of magnesian or other salts from sea-water is merely the deposition, without active chemical change and consequent change of volume, of bodies which already exist there in solution.

Summing up the facts of which undoubted evidence has been produced, it may be stated that an excess of caustic lime or caustic magnesia causes (1) disintegration by the expansion due to hydration; and (2) being soluble, when conditions permit of their washing out, they leave the concrete in a honey-combed state.

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<sup>1</sup> Brande and Taylors' Chemistry, p. 423.

## PHYSICAL AND CHEMICAL TRANSFORMATIONS.

If dry Portland cement is dropped through water into a mould, the cohesion is imperfect, and the mass resembles a block of friable sandstone, each particle crystallizing separately and without cohesion. In the same way Portland cement grout, containing 50 per cent. by weight of water, if poured through water into a mould, gives analogous results to the above, the cohesion of the block, if allowed to stand a few hours, being about double that when taken immediately after gauging.

TABLE OF COMPRESSIVE STRAINS AT TWENTY-EIGHT DAYS.

Size of Block.	How made.	Crushing Strain.
Cubic Inches. 2½ths . . . .	Neat cement poured in dry . . . .	Lbs. per Square Inch. 1,900
" . . . . {	Cement grout poured into mould, through water, 3 minutes after mixing . . . . }	950
" . . . . {	Cement grout poured into mould, through water, 3 hours after mixing . . . . }	1,900

On the other hand, a sack or barrel of cement, from the compactness of the particles forming it, after submersion, sets into a mass of intense hardness and density. Much light would probably be thrown upon the problems of hydraulicity and cohesion by microscopic examination of the physical changes induced under varying conditions. The chemical changes which take place during the setting and hardening of Portland cements, appear to hinge upon the relative proportions of lime and alumina silicates present in the raw materials. Mr. E. Fremy<sup>1</sup> and other chemists have shown that  $\text{SiO}_2$ ,  $\text{CaO}$  and  $\text{SiO}_2 \cdot 2\text{CaO}$  do not develop characteristics comparable to those of hydraulic cements, the addition of water merely resulting in a paste which slowly dries without the phenomena of setting. Mr. H. Le Chatelier,<sup>2</sup> however, proved that the tricalcic silicate ( $\text{SiO}_2 \cdot 3\text{CaO}$ ) possesses the quality of setting with water. Aluminates of lime were in a similar manner produced by Mr. Fremy by calcining pure lime and alumina at different temperatures. Alumina proved to be an excellent flux

<sup>1</sup> Comptes Rendus de l'Académie des Sciences, vol. ix. p. 993. See also Annales des Mines, vol. ix. p. 505.

<sup>2</sup> H. Le Chatelier's "Recherches Expérimentales sur la constitution des Mortiers Hydrauliques," p. 56.

for lime; and the aluminates of lime, represented by the following formulas,  $\text{Al}_2\text{O}_3 \cdot \text{CaO}$ ,  $\text{Al}_2\text{O}_3 \cdot 2 \text{CaO}$ , and  $\text{Al}_2\text{O}_3 \cdot 3 \text{CaO}$ , when reduced to powder and moistened, produced hydrates of great hardness, and possessed the property of agglomerating inert substances— $\text{Al}_2\text{O}_3 \cdot 2 \text{CaO}$ , when combined with up to 80 per cent. of sand, binding together the mass into a block of artificial stone. One important factor in the experiments was that an intense heat was essential to develop the maximum of hydraulicity. A secondary effect is due to the production of silicates of lime, containing 30 to 40 per cent. of silica, and approximating to the formulas  $\text{SiO}_2 \cdot 2 \text{CaO}$  and  $\text{SiO}_2 \cdot 3 \text{CaO}$ . Mr. Fremy showed that the function of these bodies in the setting of cements is to combine, under the influence of water, with the free lime in cement. Opinions are radically conflicting on the subject of the chemical grouping essential to hydraulicity, but cement makers agree that a minimum percentage of alumina of 7 or 8 per cent. is necessary in sound Portland cement. By grinding powdered slaked lime with cement clinker, higher tensile strains are attained in short-term tests. A clear knowledge of the chemical function of the lime in the setting of Portland cement would afford a clue to many obscure problems of great practical importance. The results given in Appendix VII show the analyses and tensile strength of two samples of cement burnt in a different manner, but made from slurry taken from the same back, that containing the lesser quantity of lime giving the higher results. The Author thinks that, in the majority of cements now in the market, the degree of heat applied, and the time for which it is maintained, result in the production of comparatively rudimentary chemical compounds, in which the excess of silica factors pairs off with an excess of lime, the result being a feeble chemical alliance. When the quantity of lime present is greater than these silica factors will neutralize, a "blowy" cement results. He considers that the cements possessing the most perfect hydraulic qualities are those in which the metamorphosis is most complete, and the most complex chemical compounds result.

The Author, in conclusion, desires to express his thanks to the many friends who have assisted him in the preparation of this Paper, and notably to Mr. Joseph Cash, M. Inst. C.E., engineer and manager of the Brighton and Hove Gas Works; Mr. Arthur J. Jack, Assoc. M. Inst. C.E.; Mr. J. L. Spoor, of Messrs. Hunter, Taylor, and Spoor, Greenhithe; and Mr. Charles Baker, manager of the Reliance Portland Cement Works, Rochester.

# APPENDIXES.

## APPENDIX I.

### ANALYSIS OF PORTLAND CEMENT PRODUCED UNDER THE AUTHOR'S SUPERVISION.

Lime . . . . .	61·05
Magnesia. . . . .	0·76
Oxide of Iron. . . . .	3·19
Alumina . . . . .	10·10
Potash. . . . .	0·54
Soda . . . . .	0·80
Sulphuric acid . . . . .	0·85
Carbonic acid . . . . .	mere traces.
Silica . . . . .	22·22
	<hr/>
	99·51

### COMPARATIVE ANALYSES IN SEQUENCE.

Constituents.	Chalk.	Clay.	Slurry.	Cement. (Clinker and Powder.)
Carbonate of lime . . . . .	73·50	1·40	77·57	60·65
Silica (in combination) . . . . .	..	24·53	7·00	21·85
Silica (free). . . . .	0·50	16·49	5·32	0·80
Alumina. . . . .	0·08	20·60	6·00	8·67
Carbonate of magnesium . . . . .	0·56	1·89	0·75	1·26
Potash and soda . . . . .	..	2·90	0·83	0·82
Iron Peroxide . . . . .	..	5·72	1·64	2·93
Water dispelled at 212° Fahr. . . . .	25·00	26·54	..	..
Carbonic acid . . . . .	..	..	..	0·52
Sulphuric acid . . . . .	..	..	..	1·18
Sulphides and loss . . . . .	..	..	..	1·39



## APPENDIX II.

## SPECIFICATION FOR PORTLAND CEMENT.

The cement to be of a uniform dark grey colour, and to comply with each, and every one of the following conditions and tests :—

*The Specific Gravity* shall not be less than 3·1, after drying for fifteen minutes in a desiccator at 212° Fahrenheit; and this shall be ascertained by a Schumann, or other approved apparatus.

*Tensile Strength*.—Not less than twenty sample test-briquettes of approved shape, and of 1 inch by 1 inch, or other approved section, are to be made from the bulk of the different consignments, twelve being gauged neat, and eight with 3 parts of normal sand. They shall be placed in  $\left[ \begin{smallmatrix} \text{fresh} \\ \text{sea} \end{smallmatrix} \right]$  water twenty-four hours after gauging, then steeped in  $\left[ \begin{smallmatrix} \text{fresh} \\ \text{sea} \end{smallmatrix} \right]$  water six days, and shall, at three, seven, and twenty-eight days respectively, from the date of gauging, successfully resist the following tensile strains applied in a machine to be supplied, or approved by the engineer :—

Neat Cement.	Not less than an Average of	Cement 1 part, Normal Sand, 3 parts.	Not less than an Average of.
Days.	Lbs.	Days.	Lbs.
3	180	7	120
7	350	28	200
28	550		

The rate at which the tensile strain shall be applied shall be 100 lbs. in ten seconds. Normal sand shall be quartz sand of approved quality, the whole of which passes through a sieve of 400 meshes per square inch, and the whole of which is retained on a sieve of 900 meshes per square inch.

*Over-liming*.—The engineer, or his agent, may apply such tests, with a view to determine any excess of lime, as he considers necessary, such as plunging test-pats into fresh water or sea-water immediately on gauging, exposing the same to heat in a wet or dry state, roughly gauging balls of sand and cement with sea-water, and exposing the same immediately in sea-water, &c.

*Fineness*.—The cement shall be uniformly ground, free from coarse clinker; and samples taken at random shall all pass through a sieve of 1,600 meshes per square inch, and leave a residue by weight of not more than 35 per cent. on a sieve of 5,000 meshes per square centimetre (32,257 per square inch). Should the proportion of residue exceed 42 per cent. on the latter mesh, the cement will be rejected; and if the residue be more than 35 per cent., and less than 42 per cent., the cement may be used, but a proportionate increase in the specified quantity of cement per cubic yard of concrete shall be made.

The contractor, or his agent, may be present at the time of taking the samples from the bulk cement, also when the briquettes are gauged, and subsequently broken, and during every operation necessary to prove the quality of the cement.

*Gauging*.—The proportionate quantity of water by weight used in gauging shall be correctly recorded, and also the temperature of the air, and that of the cement, at the time of gauging. Observations of the time the cement takes in setting are also to be recorded. Preference will be given to those makers who can produce a chemical analysis of the cement offered, and also an independent record of periodical calcimeter tests, and of tests by compression.

## APPENDIX III.

## EXPERIMENTS ON RESISTANCE OF PORTLAND CEMENT TO HYDROSTATIC PRESSURE.

*Series A. Experiment to ascertain the best proportions.*—A series of cast-iron, 12-inch, double collars were placed on sheet iron, and filled up 3 inches deep with the following mixtures:—(1) cement run in as grout; (2) cement gauged stiff; (3) cement 1 part, fine compo sand 1 part; (4) cement 1 part, fine compo sand 3 parts.

When the mixture was fairly set, the sheet iron was removed, and the collar filled with water, which was therefore free to travel through the cement material. The following Table shows the results obtained:—

Mixture.	Time allowed to set.	Loss of Water in 24 Hours.	20 Days after. Loss in 24 Hours.	Remarks.
	Hours.	Inches.		
1 . .	36	$\frac{1}{2}$	Sound	{ The leakage was between the junction of the mixture and the iron.
2 . .	24	Sound	Sound	
3 . .	48	$\frac{3}{4}$	{ Slight leakage, bare $\frac{1}{4}$ inch.	{ The leakage was as before, and also through the mixture. Ditto, mixture very porous.
4 . .	72	1	1 inch.	

*Series B. To ascertain whether the best mixture in Series A would resist a given head of water.*—Mixture 2 was selected, and filled into the end of a flanged spigot pipe of 6 inches diameter, so as to form a plug 6 inches thick. It was allowed to set for forty-eight hours, and then the riser pipe was connected, and water gradually run in until 26 feet head (11·27 lbs. per square inch) was reached. A slight leakage appeared round the junction of the cement and the iron, and also through the cement itself, in the form of beads of moisture, some yellowish discharge forming on the surface of the cement. The loss of water commenced at one pint in the first ten hours, and gradually decreased, until, on the eleventh day, the leakage entirely ceased. Fresh water was used in these experiments; and the temperature of the air varied from 51° Fahrenheit maximum to 42° Fahrenheit minimum.

A further set of experiments were undertaken to ascertain the extent of the penetration of cement deposited on the surface of a mass of rough concrete. A mixture of 1 part cement, 3 parts beach, and 3 parts coarse sand, was filled into a 12-inch cylinder, and allowed to set. A head of 30 feet of fresh water was then applied; and the loss of water per twelve hours was found to be 1·5 gallon at one day, 1·2 at three days, 1·0 at seven days, and 1·0 gallon at ten days.

As this leakage appeared to be constant, the cover of the cylinder was removed, and one pint of dry cement was stirred into the water, and allowed to deposit itself evenly over the surface of the concrete. The loss of water per twelve hours was now 0·85 gallon at one day, 0·80 at three days, 0·80 at seven days, and 0·80 gallon at ten days.

It was found that the cement added had not set, but had the appearance of mud on the surface of the concrete, and probably a similar quantity of clay

would have produced similar results. In practice, the action of the tide would have instantly removed such a deposit of cement grout, there being no sign of penetration or adhesion to the mass.

In another series of experiments, the influence of a thin veneer of cement over the surface of rough concrete in preventing filtration was tested. Cast-iron, spigot, 12-inch pipes were filled with loosely knit concrete, in the proportions respectively of 7 to 1 and 9 to 1, with a plug of concrete to the length of 12 inches. In this state, the porosity of the concrete was extreme, the water flowing through freely. The thinnest possible skin of cement was then floated over the inner face, and allowed to set, the average thickness being less than  $\frac{1}{8}$ -inch. A head of 30 feet of water was then applied; but there was not the slightest percolation of water at this pressure, proving that such a hydrostatic pressure may be resisted by a skin of cement alone, and also showing the adhesion of the concrete to the iron pipe. The results of these experiments bear out the opinion expressed by the Author in his Paper on "Harbour Improvements at Newhaven, Sussex," that the essential condition to a concrete structure in the sea is "to form a dense skin constituent with the rest of the mass."<sup>1</sup> In order to further test the accuracy of this view, experiments were made by Mr. Cash with concrete of the following proportions: No. 1, Portland cement 1 part, coarse sand 2 parts, gravel 5 parts; No. 2, 1 to 2 to 7. Flanged cylinders, as in the previous experiments, were used, and filled with concrete to a thickness of 12 inches, in the above proportions, gauged with sea-water. When thoroughly set, No. 2 sample was rendered, on the inner face, with a mixture of 3 parts coarse sand and 1 part cement, trowelled on as thinly as possible, No. 1 being left without rendering. A 20-foot head of sea-water was then applied. No signs of moisture appeared on the face of No. 1 until twenty-four hours, and No. 2 remained perfectly dry for fifty hours, after which time No. 1 leaked 165 fluid ounces per twenty-four hours, and No. 2 leaked 5 ounces. The above head of water being maintained, the leakage became gradually less; and on the twenty-second day, No. 1 leaked 10 fluid ounces per twenty-four hours, and No. 2 leaked 2 ounces; and on the fifty-fourth day, the leakage for No. 1 was 42 ounces in twenty-four hours, and for No. 2 it was 4 ounces. The inner, or pressure side of the concrete was clean, the outer, or air surface of the concrete being covered with a white material, an analysis of which is given below.<sup>2</sup> Further experiments were made to test the value of liquid grout when applied to rough concrete. A plug of porous concrete was filled into a cylinder as before. The upper portion of the cylinder was filled with water, and a 5-foot head maintained. Cement grout was then run in, but it did not set, or appreciably reduce the leakage through the concrete,

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 103.

<sup>2</sup> Of this deposit, 6·5 per cent. was soluble in water, and 93·5 per cent. insoluble. The soluble portions consisted of sulphate of magnesia and chlorides of magnesia and soda. The analysis of the insoluble portion was as follows:—

Silica . . . . .	2·90
Alumina . . . . .	3·00
Lime . . . . .	42·56
Magnesia . . . . .	7·92
Carbonic acid. . . . .	38·00
Expelled at 212° Fahrenheit . . . . .	5·62
	<hr/>
	100·00
	<hr/>

merely forming a mound upon its surface of the consistency of soft mud. Mr. Cash found that the last coat of neat cement rendering ( $\frac{1}{4}$ -inch thick) of a small gas-tank was lifted and made rotten by the hydrostatic pressure due to a spring breaking out below the tank, whilst the rough rendering ( $\frac{3}{8}$ -inch thick) was left intact. This result was subsequently illustrated by covering one end of a tin cylinder with canvas, putting into this a thickness of 1 inch of neat cement of the consistency of dough, and placing the tin in a tank of water. The tin sank in ten minutes, when the finer particles of the cement were found forming a scum upon the surface of a thickness of  $\frac{1}{8}$  inch, the cement below being left in a rotten and friable condition.

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#### APPENDIX IV.

##### EFFECT OF FROST UPON CEMENT BRIQUETTES.

*No. 1 Series.*—Gauged in water of 55° to 60° Fahrenheit, and immersed at a similar temperature, the tensile breaking strain per square inch was 540 lbs. at seven days, and 585 lbs. at fourteen and twenty-eight days.

*No. 2 Series.*—Gauged as above, and exposed for forty-eight hours (setting being unusually slow) to temperatures ranging between 30° Fahrenheit maximum to 22° Fahrenheit minimum; then placed in water exposed in the open air. The temperature during the following five days ranged between 41° Fahrenheit maximum, and 22° Fahrenheit minimum, the briquettes being embedded in ice. After seven days' test, the temperature was slightly above freezing by day, and two or three degrees below at night; but the ice did not thaw on the surface of the water. The tensile breaking strain amounted to 357 lbs. per square inch at seven days, 552 lbs. at fourteen days, and 595 lbs. at twenty-eight days. Cement of specific gravity of 3.125 was used; and the above results are each the average of four briquettes.

## APPENDIX V.—LONG-TERM TESTS OF PORTLAND CEMENT.

These tests were made by applying breaking loads to the centres of bars of neat cement, gauged with, and immersed in sea-water. The tests in the first column, in each case, were obtained by gauging cement to the consistency of mortar; those in the second column, in each case, by pouring liquid cement grout into moulds. Tests at 7 days taken as 100.

English Cements.	1 Month.		3 Months.		6 Months.		9 Months.		1 Year.		18 Months.		2 Years.		2½ Years.		Increase per cent. over 7 days' test.	Decrease per cent. under 7 days' test.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.		
A . . . {	40.9	49.6	63.2	77.6	80.4	108.9	39.9	30.1	42.3	25.2	37.4	13.1						
B . . . {	55.7	22.4	92.1	83.5	122.9	88.2	136.6	117.2	132.2	130.1	118.2	104.5	127.7	167.4				
C . . . {	78.6	60.8	98.1	117.1	131.9	139.5	162.0	13.9	200.6	24.4	32.9	16.3	88.5	30.2				
D . . . {	14.6	14.8	57.5	60.0	58.5	60.9	58.5	33.9	24.3	23.9	31.7	46.5						
Mean average result . .	47.45	36.9	77.72	84.55	98.42	99.37	99.25	31.82	66.55	26.35	4.05	15.3	108.1	68.6				
French Cements.																		
A . . . {	60.7	80.2	43.9	95.7	42.3	90.1	51.3	112.5	46.8	101.1	26.6	86.9	14.4	69.9				
B . . . {	131.8	75.6	139.1	96.8	142.8	123.1	129.1	104.5	21.2	33.3	70.4	59.7	76.6	59.7				
C . . . {	75.9	57.8	82.2	102.6	91.7	49.5	27.2	54.7	2.2	54.9	42.5	63.3	63.7	60.3	62.1	70.2		
D . . . {	70.3	83.9	89.7	98.8	78.3	117.1	82.6	111.8	72.1	111.8	67.2	97.1	84.4	111.5	82.4	74.5		
Mean average result . .	81.67	74.37	88.72	98.47	88.78	94.95	17.65	68.52	23.87	31.17	4.77	15.2	10.37	15.35	10.15	2.15		

## APPENDIX VI.—RESULT OF EXPERIMENTS TO SHOW ABSORPTION OF BRICKETTES OF PORTLAND CEMENT IMMERSSED IN SEA-WATER.

These results are in each case the average of six tests, and were obtained by gauging with fresh-water briquettes of 1 square inch section, and immersing the same at the Pier-Head, Newhaven Harbour, forty-eight hours after gauging.

Temperature of Cement and Air 57°; Residue 10 per cent. on  $50 \times 50$  mesh.

Proportion of water by weight	Neat	1 to 1	1 to 2, 3, and 4 respectively.
$\frac{7\frac{1}{2}}{7\frac{1}{2} \text{ to } 40}$		$\frac{7\frac{1}{4}}{7\frac{1}{4} \text{ to } 40}$	$\frac{7 \text{ to } 40}{7 \text{ to } 40}$

TABLE OF AVERAGE WEIGHTS AND BREAKING STRAINS IN TENSION.

Proportions.			14 Days.			28 Days.			3 Months.			6 Months.		
	Before Im- mersion.	After Im- mersion.	Breaking Strain.	Before Im- mersion.	After Im- mersion.	Breaking Strain.	Before Im- mersion.	After Im- mersion.	Breaking Strain.	Before Im- mersion.	After Im- mersion.	Breaking Strain.	Before Im- mersion.	After Im- mersion.
Neat . . . .	Grammes, 227·5	Grammes, 238·8	Lbs. per Sq. Inch, 446·7	Grammes, 213·8	Grammes, 219·6	Lbs. per Sq. Inch, 570·0	Grammes, 213·7	Grammes, 216·3	Lbs. per Sq. Inch, 448·3	Grammes, 212·8	Grammes, 239·5	Lbs. per Sq. Inch, 495·0	Grammes, 212·8	Grammes, 239·5
1 to 1. . . .	233·2	243·7	255·0	215·7	220·6	291·7	217·2	218·0	269·2	228·2	250·0	348·3	228·2	250·0
1 to 2 . . . .	227·0	238·5	123·3	212·2	217·0	166·7	212·5	213·6	185·0	219·5	239·0	242·5	219·5	239·0
1 to 3 . . . .	221·5	235·2	..	203·2	207·8	..	205·9	211·1	135·0	210·7	232·2	195·0	210·7	232·2
1 to 4 . . . .	211·2	222·2	..	206·7	211·7	..	205·1	212·1	..	190·5	214·8	142·5	190·5	214·8

## APPENDIX VII.

RESULTS OBTAINED FROM BURNING, IN A DIFFERENT MANNER, TWO SAMPLES OF SLIP FROM THE SAME BACK.

—	Sample A.	Sample B.
Carbonic acid . . . . .	0·35	1·25
Magnesia . . . . .	0·65	0·75
Insoluble silica . . . . .	1·50	2·84
Soluble silica . . . . .	20·80	19·50
Alumina and ferric oxide . . . . .	16·25	12·50
Lime . . . . .	54·85	56·55
Alkalies and loss . . . . .	5·60	..
Alkalies and loss, with traces of sulphate of lime . . . . .	..	6·61
Total . . . . .	100·00	100·00

Tests.	Sample A. Lbs. per Inch.			Sample B. Lbs. per Inch.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
<i>Neat cement—</i>						
7 Days in water .	600	580	593½	450	390	420
14   "   "	660	640	647½	500	450	470
28   "   "	850	750	783¾	600	500	551¾
<i>3 Standard sand to 1 cement—</i>						
7 Days in water .	240	220	223¾	120	100	108½
14   "   "	300	250	261¾	165	150	153¾
28   "   "	430	370	383¾	190	160	175

# APPENDIX VIII.

## FANCY TESTS.

Some discussion has taken place as to the advantage of adding sugar, salt, or soda to concrete. The following comparative tests in compression, at three months, have been undertaken to ascertain what effects result from the addition of varying proportions of these materials. The same sample of cement was used throughout the trials; it had a specific gravity of 3.030 (weight, 113 lbs. per bushel), and was ground to leave a residue of  $9\frac{1}{2}$  per cent. on a 50 by 50 mesh sieve. The following Table gives the average tests in tension and compression:—

Conditions.	Neat. Average per Square Inch. Tensile Strain.	3 Standard Sand to 1 Cement. Average per Square Inch. Tensile Strain.	Average Crushing Strain at 3 Months. Per Square Inch.
	Lbs.	Lbs.	Lbs.
28 Days' immersion in fresh water . . .	574	192	Neat— 7,392
3 Months' immersion in fresh water .	{ Did not break at 600 lbs. }	216	3 Standard Sand to 1 Cement— 2,112

*Addition of Sugar.*—Six compression blocks of 8 square inches were gauged with 20 per cent. of fresh water, and with the addition of 5 per cent., by weight, of common brown sugar. Three of these fell to pieces in the water, or in adjusting in the machine. The remaining three gave an average breaking strain of 2,557 lbs. per square inch.

Six compression blocks of 16 square inches, of 3 of standard sand to 1 of cement, were gauged with 10 per cent. of fresh water, and with the addition of 5 per cent. of sugar as before. Three of these broke in adjusting in the machine, and the remaining three gave an average breaking strain of 1,358 lbs. per square inch.

Twelve compression blocks (six with, and six without sand, as above) with  $2\frac{1}{2}$  per cent. of sugar all fell to pieces; and the contraction was more marked with these samples than with those containing 5 per cent.

In all cases, a large quantity of gelatinous tasteless substance was exuded from the blocks. In setting, the blocks contracted greatly, more especially the samples without sand.

*Addition of Soda.*—The following Table gives the average results obtained with the addition of  $2\frac{1}{2}$  per cent. and 5 per cent. respectively of common washing soda.



Composition of Blocks.	Area of Blocks.	Average Crushing Strain per Square Inch.	Conditions.
	Square Inches.	Lbs.	
Neat Cement— 2½ per cent. soda . . } 20 per cent. water . }	8	2,862	{ 3 Months' immersion in fresh water.
Neat Cement— 5 per cent. soda . . } 20 per cent. water . }	8	2,841	„
3 Standard Sand to 1 Cement— 2½ per cent. soda . . } 10 per cent. water . }	16	855	„
3 Standard Sand to 1 Cement— 5 per cent. soda . . } 10 per cent. water . }	16	1,241	„

*Addition of Common Salt.*—The following Table gives the average results obtained with the addition of 2½ per cent. by weight of common salt in solution.

Composition of Blocks.	Area of Blocks.	Average Crushing Strain per Square Inch.	Conditions.
	Square Inches.	Lbs.	
Neat cement, and 20 per cent. water . . }	8	3,590	{ 3 Months' immersion in fresh water.
3 standard sand to 1 cement, and 10 per cent. water . . . }	16	932	„