Firstly, may I thank this Society for the honour conferred on me by inviting me to read this paper before its members.

The subject suggested to me by your worthy President was "Cement and Its Uses," but as cement is only a component part of concrete, and learning that such a paper has not previously been read before your Society, I asked permission to change the title to "The Concrete Age," for undoubtedly the period we are now living in is a "concrete age." Your President was gracious enough to grant my request, and I thank him.

As a subject for consideration it is tremendously embracing, and I could not possibly cover it in the time allotted to me to-night, but will endeavour to make it as comprehensive as possible.

Again, as a subject, it could become so technical and controversial, that were I to stick rigidly to its purely scientific side, I could picture myself at the end, and you good people, too, so confused and involved that question time would resolve itself into an endurance test, and that must be avoided at all cost.

I would here point out that I am not a Cement Chemist, but am only an Engineer, who, like yourselves, finds lot of uses for the remarkable product we are considering to-night. Therefore I propose to make this paper just a talk on the birth and history of cement, and the tremendous influence it has exerted on the development and progress of the world, and to leave some thoughts that may linger with us, compelling us to realise what a wonderful age we are living in, and the part we are playing, whilst using cement, in making this old world of ours a better place for ourselves, our children, and the generations to follow.

Though, strictly speaking, all glue-like materials should be classed as cements, common usage, however, tends to reserve the name "Cement" specifically to describe "Portland Cement." Perhaps not surprising, when one considers the versatility of Portland Cement concrete, which has led to its application in a remarkable variety of structures, and the consequential extraordinary development of the Portland Cement industry throughout the world.
I am taking it for granted that you already know that Portland Cement is little more than 100 years old, and it was then a very different material from the high-grade cements that are being manufactured to-day. I do not mean that cement and its use are only 100 years old. That is not so, and just as briefly as I can I will mention its origin and trace the evolution of this remarkable man-made stone.

Its origin goes back to prehistoric days when the human race, realising its need for shelters, used mud for fashioning them. As population increased and dwellings necessarily became larger, the mud was sun-baked into bricks, but freshly mixed mud was still retained as the cementing agency to keep these bricks in place, and quite extensive buildings were constructed by these primitive means, of which authentic evidence is still being discovered.

That this construction met all requirements of those days can readily be understood, as civilisation was then all confined to those portions of the East where the climatic conditions were particularly dry and local rainfall negligible, and mud, as a cementing medium, sufficed.

However, population and civilisation continued apace, and the domestic needs and increasing culture of the people demanded more commodious and permanent structures. Naturally the builders turned to local materials for their requirements, and so limestone, gypsum, marble, and even basalt and granite, were used, the blocks of which were roughened, grooved, and dovetailed, so that, when put together, they became stable enough to resist wind and other stresses. The size of these structures still continued to increase, and it was realised that some other agency, besides the shaping of the blocks, was necessary to prevent movement and increase strength.

The early Assyrians used bitumen for this purpose, as adjacent regions yielded large quantities of this excellent bonding material. It is still being used the world over, not so much now for structural purposes as for the bonding of roads.

The early Egyptian era followed closely, with buildings still increasing in size, and calcareous materials were adopted for the cementing of the building blocks which were bedded down on slaked lime. Just how far lime goes back it would be impossible to determine, as the Pyramid of Cheops, now 5000 years old, has lime as a bedding material. Examples are still being unearthed of prehistoric masonry, where the stone and mortar are of similar composition, the only substantial difference being that the stone, used for the cement, had been
prepared by burning. One notable authority, Bertram Blount, Fellow of the Institute of Chemists, quotes as an example of this in the Great Pyramid, which, he says, was constructed of crude gypsum, the cementing mortar being the same substance burnt.

It will be noted that, in those early days, the areas where lime was used as a mortar were sparsely timbered, so that it is natural to conclude that the discovery of lime, as a cement, was just as empirical as that of glass. Evidently some ancient unknown pioneer found that when the calcareous rocks were subjected to heat, they underwent a change, became softer, were easily pulverised, and when mixed with water, would set, adhere to stone, and also become hard. Another example of its use, antedating any known history, is evidenced in the remains of a temple on the island of Cyprus, which is supposed to be the oldest ruin in the world, and lime mortar is found between the stones.

May I here quote another great authority on Ancient Egypt, Dr. Desch, who says, in describing some massive masonry of those periods: “It is therefore fairly well established that in these early days of our world history, long, long before 2000 B.C., calcareous materials were burnt and used as cement, quite universally, but without discrimination between the siliceous or sulphate classes, and whilst cement, thus produced, was eminently suited to the dry atmosphere of Egypt, in those days, it would not suit present-day conditions, for it is generally admitted that the Egyptian climate has changed over the years, even since the erection of the Assuan Dam in 1898, and that rain is not as rare as in bygone years.”

Let us leave Egypt for a moment and travel farther east, to that ancient, and even yet, only partially known country, China, and here we find it is quite impossible to determine the date when a cementitious mortar was first used, but historians and later-day explorers, one of whom, W. E. Geil, that great American traveller, quoted cement’s antiquity, and Mr. Geil, in describing one of the wonders of the world, the Great Wall of China, says: “There it still stands, while the walls of Hadrian, the Roman Emperor of 76 to 138, who built a wall in England between Newcastle and Carlisle, and Antoninus Pius, who between 138-161 built the wall between the Firth of Forth and the Clyde, have crumbled to the ground, and their course can only be indistinctly traced here and there.” A very ancient commentator states that "extensive portions of the Great Wall were built by local kings, very many centuries before the first Emperor of the Ts'in Dynasty took the construction of the Great Wall in hand as a
whole.” This first emperor, She-Hwang-ti, 214 B.C., determined to “complete the barrier all along the north of his vast empire to keep off marauding hordes.” This wall is now 1500 miles in length, 25 ft. thick at ground level, 15 ft. thick at the top, and from 15 to 30 ft. high. It is made of blocks cemented together, and forming two strong retaining walls, filled with stones and mud. So here again, mud was used for the cementing agency in the mass filling. The whole surface is also covered with bricks, cemented together.

So we could go on tracing the uses to which cement was put throughout the ages, but time will not permit, so let us return again to the Middle East.

Here we find that the early Romans also made extensive use of a calcareous cement, not only in their buildings, but in roads, bridges, and aqueducts, and the results of their craft are still existent and are constantly being uncovered, there being hardly a country in Central and Western Europe, into which the Romans penetrated, where buildings and roads, in a really remarkable state of preservation, have not been found in recent years. Plinius, the elder, wrote extensively concerning lime; and it is interesting to note that he complained of “the malpractice of builders who skimmed the lime in their mortars.” Apparently human nature varies but little down the ages.

Unfortunately the gap between the Ancients and the Romans is not very well bridged in the uses of lime, but it is reasonable to assume that as civilisation spread westerly and northerly from the dry areas of the East, taking with it the art of the architect and the builder, the need for a cementing material to resist the altered weather conditions became increasingly urgent. Lime had been used in the early days mentioned, and you know that, when slaked with water, it makes an admirable plastic mortar paste, with splendid adhesive qualities. You know also that it shrinks badly on drying. Therefore, an inert filling material has to be added to it, to keep its volume approximately constant. Our ancient forebears showed their astuteness and sound building and engineering ability by adding the fine sands, which abounded in the East, as that filler, and we are still following the practice of those ancient craftsmen.

The Romans, however, did understand the use of calcareous cements exceedingly well, as their buildings testify. They, too, were probably the first people to deliberately make a hydraulic cement. By that I mean a lime which, when mixed with other materials, would set under water, and resist all
its actions without disintegration. They achieved this result probably by the addition of volcanic ash to the slaked lime and sand.

After the fall of this then mighty empire, there was a definite decay in civilisation, one of the most pronounced results being the decline in the art of the builder, particularly in one very important phase, the making and use of good cementitious mortars. Rule of thumb was evidenced almost everywhere. Limestones were used, but quite regardless of their suitability, the builders just taking them promiscuously from the nearest deposits to their jobs. It was fortunate that some of these limestones were siliceous, and also that puzolanic materials were to be had in the same neighbourhoods, and so quite good cements were made, but so accidentally and casually that successful construction was very limited, and failures must have been many. Just how many it is difficult to estimate, as their natural disintegration and consequent destruction removed all evidence of their existence.

This chaotic state lasted for very many years and all over Europe, and it was really not until 1756, when Robert Smeaton, the great British engineer, who was the father of Civil Engineering in Great Britain, was commissioned by Parliament to undertake the replacement of the Eddystone Lighthouse (wood), that any marked improvement took place. Smeaton, faced with the tremendous task of having to contend with rising and falling tides, the lashings of terrific storms, the limited space and time he had for the preparing and placing of his building materials, reviewed all the then known mediums of cementing masses of masonry, but could not find that any limestones had been deliberately or intelligently chosen for their hydraulic qualities. To use his own words he said: "I seriously began to consider the great importance that it was likely to be to our work to have a cement, the most perfect that was possible, to resist the extreme violence of the sea, and on consideration of this matter it appeared that nothing of the resinous or oily kind (bitumen) could have any place in our work, as it would require the surface to be dry to enable it to make a complete adhesion, whereas the getting anything completely dry was one of our greatest difficulties. It seemed, therefore, that nothing in the way of cement would answer our end but what would adhere to a moist surface, and become hard without ever becoming completely dry." Smeaton then commenced a series of experiments, using many kinds of limestones, particularly from Plymouth and Aberthaw, and after burning
and slaking it, mixed it with trass and other forms of silicas to get adhesion and hard set, for he saw, and again to use his own words, "that not only much of the beauty and neatness of the work, but its solidity, too, would depend upon getting a cement that would, in spite of water, almost continuously driven against it with every degree of violence, become so firm a consistence in itself and adhesion to the stone, that it should lie fair and flush in the joints, and so as to compose one even regular surface with the stone, and without needing hoops of iron or copper to surround the horizontal joints, as seems to have been the expedient of Mr. Winstanley." At the end of a full winter's ardent and intense experimenting, Smeaton said "he had now found a species of materials and a method of compounding them very competent to his purpose." He saw there was a great difference in the effect, which arose from the different nature of the lime, burnt from the various limestones, and that its acquisition of hardness under water did not depend on the natural hardness of the limestone, inasmuch as chalk lime appeared to be as good as that burned from Plymouth marble, and that Aberthaw lime was greatly superior to either for the purpose of aquatic buildings, though scarcely as hard as Plymouth marble. Smeaton also carried out many experiments for ascertaining the purity of the limestones he used, after which he said: "I am convinced that the pure limestone was not the best for making mortar, especially for building in water, and this brought to my mind a maxim I had learned from workmen—that the best lime for the land was seldom the best for building purposes; of which the reason now appeared, which was that the most pure lime affording the greatest quantity of lime salts, or impregnation, would best answer the purposes of agriculture, whereas, for some reason or other, when a limestone is intimately mixed with a proportion of clay, which by burning is converted into brick, it is made to act more strongly as a cement." This suggested to Smeaton that an admixture of clay in limestone, when treated in the manner he used, was most suited for the aquatic work he had in hand, and was the forerunner of all later practice, and which has proved to be correct right up to the present day. It is therefore quite evident that, even as late as the middle of the eighteenth century, the only method of deciding on the suitability of calcareous cements for any particular purpose was by its local reputation. Thus Smeaton heard of Aberthaw lime, the blue lias limestone running through this country; and layers of calcareous shale also ran through it, the ingredients of an excellent cement-making compound,
when suitably mixed. But Smeaton did not then know that Aberthaw limestone in those days meant only the stones washed down from the cliffs on to the beaches. These stones, even to-day, are collected and sent to South Wales to be burnt for cement. The trass, which Smeaton used, was then known as “Dutch Tarras,” and came from old volcanic deposits on the Rhine, but was shipped to England through Holland, hence the term Dutch. Smeaton’s final pronouncement of the results of his experiments was: “I was fortunate to succeed entirely to my satisfaction, and perhaps in a degree unknown before, and have made much use since of the experience which I then acquired, and have had frequent occasions and opportunities of communicating it to others. On this subject I was apprised, that two measures of slaked lime, in the dry powder, mixed with one measure of Dutch Tarras, and both very well beat together to the consistency of a paste, ‘using as little water as possible,’ was the common composition to use in the construction of the best water-work, both in stone and brick, and which, after being once set, would afterwards become hard, without ever being completely dry; nay, it would, in time, grow hard under water. This therefore seemed to be the kind of cement adapted to our use.” It can thus be readily conceived that Smeaton left no stone unturned or avenue unexplored in his experiments to secure what he termed should be “a cement, the most perfect that was possible,” and in his corner of science did work which is as permanent as his wonderful lighthouse was stable. Eddystone Lighthouse stood till 1882, a beacon of safety for 120 years, and it was only a fissure in the foundation rock that brought about its demolition.

We could follow many other interesting phases of cement manufacture which occurred during this period if time permitted, but they were all of a similar nature to Smeaton’s experiments, and it really was not until 1824 that Joseph Aspdin, a bricklayer, of Leeds, accidentally discovered that a mixture of chalk and clay, when burnt, made a hydraulic cement. It is quite evident that Aspdin did not deliberately burn his mixture of chalk and clay to the point of incipient fusion, which we now know to be necessary, but he did recognise that it was important to get a thorough amalgamation of his raw materials by reducing them to a state approaching inpalpability. He did, however, use as high a temperature as it was possible to obtain with the crude methods then in use. He also recognised that it was necessary to grind his product as finely as he could, with the means he could command, to get the setting and hardening
he desired. That his discovery was empirical is borne out by the fact that, in the burning of his mixture, which was done in the ordinary vertical lime kilns of those days, some of it actually did clinker and formed into small nodules. These, however, were looked upon as being overheated, and were carefully picked out and thrown aside, and only underburnt material was ground. His product assumed a delicate grey colour after setting, and it so resembled the natural stone of Portland, both in colour and texture, that Aspdin, when he took out his first "Letters Patent" on 21st October, 1824, called it "Portland Cement," the name it has been known by ever since. He also got his clay from the roads. Again, it was by accident, that quite a quantity of these overburnt nodules, which had been burnt about this time and cast aside, exposed to weather conditions, were found and noticed to be in the same state as when thrown out. These were collected and ground, out of curiosity, and the resultant cement, when tested, gave results never dreamed of before, and from then on hard burning became established practice.

Aspdin opened his first factory at Wakefield in 1825, continuing the thorough mixing of his finely-ground raw materials before burning. This was done in the old bottleneck kilns, being fed into the top in alternate layers with fuel and extracted from an aperture at the bottom. Grinding was also crude, the old-fashioned millstones being the only known method of reducing it to the required state of fineness, and it is interesting to note that they were still in use 50 years ago.

It is quite natural to conclude that the quality of Aspdin's cement varied considerably, but it was the first great stride in structural development, and that he did produce a remarkably good cement is evidenced by the fact that in 1838, just three years after his factory was established at Wakefield, Sir I. K. Brunel used it for building the first tunnel under the Thames. The price at that time, at the works, was 21/- per cask, and it found a ready market, but its popularity was retarded by the influential vested interests controlling Roman Cement, which was firmly established throughout Great Britain.

Many prominent engineers and scientists in England then commenced experimenting, which contributed materially to the ultimate success of Aspdin's discovery, such as Major-General Sir C. W. Pasley, also Messrs. Frost, Francis, White, and particularly John Grant, who constructed the London drainage works in 1859, thus giving a great impetus to the industry.
In 1872 Goreham introduced the semi-wet process of mixing clay and chalk, which, besides getting a more uniform mix, proved quite a labour-saving innovation, as the raw mix, after having passed through the millstones to give it its final combination, was then pumped to the drying floors or kilns preparatory to burning.

Johnson's patent kiln was the next improvement, as he utilised the waste heat from the calcining of the clinker to dry out the next batch of wet mix.

Another revolutionary step was taken by Thomas R. Crampton, M.I.C.E., in 1877, who patented a "rotatory kiln," but he did not put his invention on a manufacturing basis. Frederick Ramson, Assoc. Inst. C.E., followed, and on 2nd May, 1885, patented a rotary kiln, which actually was to be the forerunner of the present day kiln. I'm sure a brief description would be interesting, so read his Letters Patent: "It consists of a cylindrical furnace set at a slight inclination, carried on rollers and rotated by worm gearing. At the upper end, powdered raw material is fed in by a hopper, and travels down the furnace, meeting burning producer-gas entering by a pipe. The burnt material falls into a pit, and any raw material, which may be blown back up the furnace, is caught in a settling pit, whence it can be returned to the hopper." Ransome was also under the impression that by drying and grinding the raw materials to a very fine powder, after it had been thoroughly mixed, and then passing it through the rotary kiln, that each particle would burn independently and thus obviate the necessity for further grinding, but he failed to realise that it cohered and formed small nodules when burnt. Although he was wrong in this assumption, he nevertheless realised that there would be a great saving by this continuous production, and that the cement would be more uniformly burnt than it would be when placed in masses into fixed kilns.

Wilfred Stokes next introduced an improvement on Ransome's kiln by installing an equipment for the economical and systematic use of heat, but, although very ingenious, it did not fulfil its mission and actually held up progress for nearly ten years, and really was responsible for shifting the centre of interest in the industry from England, the land of its birth, to America, where its development has been truly remarkable. Improvements in America came apace. Producer gas gave way to oil fuel, which abounded there, and it was left to Antonio de Navarro (in 1889) to introduce the modern form of rotary kiln in America. The new improvements in
this idea naturally returned to England, the first kiln of its kind being erected there in 1900. Strangely enough it does not differ in any essential respect from the earlier patterns, the alterations being practically confined to increased size and greater simplicity, especially in the burner, which is now run by a fan at comparatively low pressure, and not by an injector as formerly. This lends itself admirably to the use of powdered coal as fuel, which has become practically standard usage throughout the world.

It will be noticed that, in describing the evolution from lime mortar to Portland Cement, I have used practically all British dates and matter for my illustrations, but it must not be forgotten that England was actually the home of Portland Cement. England was also the parent of the American nation, and it is natural to conclude that in cement manufacture, as in other developments, it was not long after discoveries were made in the Old World that their significance was conveyed to and adopted by the New.

So it is not surprising that the results of Smeaton's experiments in 1757 were used to advantage in 1818, when a natural "cement rock" was discovered near Madison County, New York, where Mr. Canvass White, a prominent engineer, was engaged in the construction of the Erie Canal, and burnt it to make a hydraulic lime cement. Nor is it any stranger that Aspdin's great discovery, about 1824, of burning clinker to fusion, was actually tried out in James Frost's lime kilns at Swansecombe, America, in 1825.

Portland Cement works were first established in Germany, at Stretton, in 1852, and the Germans were quick to appreciate the value of this new building material, and with their usual thoroughness, and the substitution of scientific methods for the old rule of thumb, they produced a much better cement than any other country. They were also quick to appreciate the value of very fine grinding, and were so successful that for years German cements were looked upon as world standard.

France, too, readily grasped the significance of this new cement, and rapidly adapted herself to the new order of its making, and to-day is a centre of production of high-grade Portland Cements, but has gone further, and by the use of different raw materials and a different process also makes an Aluminous Cement, which is the most rapid hardening cement in the world.

There is now no civilised country which does not produce its own cement, and to-day the world's annual production is
100,000,000 tons. Of this great total Australia's contribution, with its population of only 6½ million and its eleven plants, is 800,000 tons, involving a capital investment of £5,000,000, and giving direct employment at these works to some 5000 employees.

Yet, when you consider that the greatest proportion of the earth's crust consists of acid oxides, and that carbonates of lime also exist in enormous quantities over its surface, and that Portland Cement, consisting as it does of basic silicates and aluminates, can be manufactured in most parts of the world, it is apparent that the growth of the industry was relatively slow in the early periods. This can be attributed to ignorance and to the prejudices of the majority of architects, engineers, and builders in the early stages of its evolution, also to the casual method of its manufacture. This resulted in the production of a very inferior material, sometimes actually dangerous to use, as its chemical instability caused its expansion to such a degree at times when in the work as actually to destroy the structure.

Another fallacious idea, too, that localised production in Great Britain, was that good cement could be produced only from the purest of chalk, and limestone and shale were considered to be only of secondary importance. However, those days have now completely vanished, and the cement chemist has made it possible to produce the highest standard Portland Cements from innumerable and varied materials. May I use Australia to illustrate this point. In Western Australia old oyster shells are dredged out of the Swan River at Perth for its cement production. In Queensland pure coral provides the raw material, whilst between these two points deposits of limestone, some so soft that it can be scooped out with steam shovels, and some so hard that it is actually used as road metal, are utilised to make cement, which complies with world standard specification.

It will thus be seen that the range of materials is wide indeed, and the old theory exploded, but it lasted long enough to cause much injury to the industry, and purely for the want of chemical and technical knowledge.

During the ramifications of this commentary, which I hope has not been too uninteresting, I have mentioned many cements. May I here give a brief description of them:—

1. **Common Lime** is made by burning relatively pure limestone at temperatures between 600° and 1200° C. It slakes on addition of water, but has not any hydraulic properties.
2. **Hydraulic Lime** is made by burning argillaceous or impure limestone at the same heats, 600° and 1200° C. It slakes with water, and has definite hydraulic properties.

3. **Natural or Roman Cement** is made by burning an impure or natural limestone at a low temperature (insufficient to vitrify). It does not slake with water, and requires to be ground to convert it into a hydraulic cement.

4. **Portland Cement** is made by burning to incipient vitrification an intimate mixture of an argillaceous substance, such as clay or shale, and a calcareous substance, such as limestone or marl, containing in the mixture the percentages of silica, alumina, and iron oxide in their proper proportions. This is burned at temperatures ranging from 1300° to 2100° C. This does not slake with water, and must be finely ground to give it its maximum strength and hydraulic properties.

5. **Puzzolan Cement** is made by incorporating slaked lime with finely-ground slag or volcanic ash, or incorporating a small proportion of Portland Cement clinker with suitably treated furnace slag or volcanic ash, and grinding the mixture intimately.

6. **Plasters** are made by heating or burning gypsum at from 100° to 140° C., and do not always require grinding, as they fall to a powder during burning. Hard plasters, however, such as "Victor Hard," are dead burnt to a much higher temperature, probably up to 200° C., and are finely ground. Neither of these plasters has hydraulic properties.

As previously stated, it is left to the chemists to determine the quantities of the raw materials required for cement manufacture, which roughly is 80% lime and 20% clay, but this average analysis of Geelong cement can be taken as general practice:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>64.9</td>
</tr>
<tr>
<td>Silica</td>
<td>22.7</td>
</tr>
<tr>
<td>Alumina</td>
<td>5.2</td>
</tr>
<tr>
<td>Iron Oxide</td>
<td>1.8</td>
</tr>
<tr>
<td>Magnesia</td>
<td>1.5</td>
</tr>
<tr>
<td>Sulphuric Anhydride</td>
<td>1.9</td>
</tr>
<tr>
<td>Insoluble and loss on ignition</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Both the wet and dry processes are still being used for cement making throughout the world. In the dry process the raw materials are first reduced to a reasonable fineness, generally in hammer mills, and are then dried before grinding, invariably by waste kiln heat, in order to avoid excessive moisture, which would make the powder so sticky that it
would refuse to flow and would choke the grinding mills, which further reduces the mixture to the necessary fineness for feeding into the kilns, where it is calcined into clinker.

In the wet process the raw materials, having been blended in their approximate ratios, are reduced to their required fineness, with an admixture of water, in ball mills, and are intimately mixed into a slurry in huge basins fitted with rotary stirrers, from which it is pumped into the rotary kilns, where it emerges as clinker. I can better explain this process by describing, in detail, the works of Australian Cement Ltd. at Geelong. Here is one of the most up to date of the world's cement plants, with a full and highly qualified staff. It will be interesting to note that the whole operation of cement manufacture at these works is mechanical, and that the product is not once touched by human hand. Naturally there is handling in the unceasing testing and analysis that go on, the laboratory staff never being idle, working in three shifts of eight hours day and night. As far as it is humanly possible the supervision is so rigid right from the time the limestone leaves the quarry, and the facilities for rectifying any changes so thorough and rapid, that there should never be the possibility of one tenth per cent. variation in the constitution or quality of the cement produced.

At most cement works the raw materials have to be obtained from different quarries, often many miles apart. Australian Cement Ltd. may therefore be considered fortunate in being able to obtain the whole of its raw materials from the one quarry, due to the fact that the top strata of limestone contains sufficient clay and the lower strata sufficient silica to provide the desired mix, when a section of the whole face is considered. The limestone consists of an unconsolidated mass of shells, corals, etc., possibly of the Miocene Age, and this mass is overlain with from 20 to 40 ft. of overburden. The stripping of the overburden is done with steam caterpillar shovels, which discharge into trucks, and are drawn to a dump by steam locomotives.

The quarry is immediately adjacent to the Moorabool River, and is worked to a depth of not only 150 ft. below the river level, but also about 100 ft. below sea level. In view of the porous nature of the limestone, it is obvious that facilities have to be provided for handling the quantity of ground water encountered. This is done by two large centrifugal pumps situated inside a concrete shaft 180 ft. deep, and so disposed that even an extended power failure would not expose the motors to submersion.
The quarry is connected with the works by railway track some three miles in length, and the floor level of the quarry is reached by an incline tunnel 4376 ft. long, being the longest in Australia, the track descending on a grade of 1 in 36. The limestone in the 120 ft. face is shot down and broken, by secondary blasting, to suitable size, and then loaded into the railway trucks by means of caterpillar shovels with a dipper capacity of 2\(\frac{1}{2}\) tons. Each truck holds approximately 17 tons; six trucks form a rake, which is hauled to the works by a 70-ton "Garrat" locomotive running on a 3 ft. 6 in. gauge. When each 100-ton train load of stone is being loaded in the quarry an average sample is taken and analysed by the quarry chemist, and the results telephoned to the works before the train arrives, so that the stone can be placed in its appropriate section of the storage—high grade, medium grade, or low grade—according to the quarry analysis.

When the rake of trucks reaches the works, it is coupled to a rope haulage, allowing the locomotive to return to the quarry immediately with empty trucks. The rope haulage spots each truck individually at a mechanical tipping device at the crusher station. The crusher is a mammoth Williams Rotary Hammer Crusher, which reduces the raw material to the size of sand at the rate of 300 tons per hour. The raw material is discharged on to a belt conveyor, which raises it to a raw storage. Here it is picked up by an electric travelling crane, which places it into its respective raw mill bin according to analysis. This crane has a 15 ft. bite and an 8-ton capacity, and is so placed that it can travel to the cement end of the works and handle the clinker also.

From the raw mill bins the raw materials are fed by gravitation on to rotary feeder tables, which regulate the feed into the raw grinding mills, together with the necessary amount of water. The raw mills, of which there are five, consist of steel cylinders 36 ft. long by 6 ft. 6 in. in diameter. These are lined inside with heavy liner plates, and carry a charge of some 36 tons of steel balls, which half fill them. The mills are driven by 500 h.p. motors, and revolve at approximately 23 r.p.m. The grinding is done by the cascading of these steel balls with the slurry, until 95% will pass through a screen having 32,400 holes per sq. in. Samples are taken from the mills at regular intervals and analysed for moisture content, fineness, lime content, etc. From these raw mills the slurry is elevated to testing and blending silos, where analyses are adjusted by addition of high or low grade lime slurry, and the necessary corrections of the proportions of iron, alumina, and silica are also made. Only after the slurry conforms in every
respect to the desired grade is it discharged to storage basins, of which there are three, each 60 ft. diameter and 12 ft. deep, and containing 2000 tons. To prevent segregation the slurry is kept constantly stirred by mechanical agitators as well as by air agitation.

The slurry is now pumped to the rotary burning kilns, two of which are the largest in Australia and among the largest in the world. They consist of steel cylinders 420 ft. long by 10 ft. in diameter, and are lined inside with highest quality fire brick. Each kiln is approximately 1200 tons in weight. It is set at an angle of 1 in 24, its weight being carried on seven tyres, each supported on two bevelled rollers, and the whole is rotated at 1 1/3 r.p.m. by 125 h.p. motors. In the first 120 ft., at the top or feed end of the kiln, about a mile and a half of heavy chain is hung in the form of spider webs across the cylinder. The object of these chains is to obtain the greatest efficiency from the coal fuel by extracting the fine gases that pass through them, and distributing the heat through the slurry during the course of each revolution.

In its passage through the kiln the slurry first gives off its moisture content, and later the carbon dioxide from the lime, until travelling down the kiln it reaches the hottest zone (the so-called sintering zone) where the chemical fusion takes place between the lime and the clay, resulting in the formation of those silicates and aluminates of lime which comprise Portland Cement.

The fuel is pulverised coal, and is blown in at the lower end of the kiln, creating a flame temperature of 3200° F. and a clinker temperature of 2800° F. During its passage up the kiln the heat temperature is reduced from 3200° F. to 400° F. The stack, which serves both kilns, carries 2800 tons of gases daily, including 600 tons of water evaporated from the slurry.

The white hot clinker, when it reaches the lower end of the kiln, drops into the 20 ft. integral cooler revolving with the kiln, where it is cooled off from 2800° F. to 400° F., giving up its heat to the induced air, which is used for the combustion of the pulverised coal. This is blown into the kiln by a large centrifugal fan blowing through a pipe into which the pulverised coal is allowed to drop, the intimate mixture burning like a gas flame in the kiln.

After passing through the cooler the clinker drops into a long steel shaker conveyor, which further cools it. This conveyor discharges into a steel bucket elevator, which finally drops it into a clinker storage of 16,000 tons capacity, where it is still further cooled, in the course of the weeks, before it
is required to be used. This storage, although roofed over, is open to the air all round.

From this clinker storage the clinker is picked up by the travelling crane and dropped into mill feed bins. The grinding mills are practically identical with those used for grinding the raw materials, and these reduce the clinker to the finest of powders, so fine that less than 5% is retained on the 32,400 screen. May I give a homely description of this fineness. It is such that the combined surface of the particles in each bag of cement total the terrific area of two acres, 7700 sq. yds., or 10,000,000 sq. inches.

In this final grinding a small percentage of gypsum is added to the clinker, for the purpose of regulating the cement's setting time. If clinker were ground by itself and mixed with water, it would set almost instantly, thus preventing concrete being placed in its required positions, consequently a retarding agent is added to delay that set, and gypsum is that agent.

When the finished cement leaves the grinding mills it is elevated into storage silos. As required the cement is extracted pneumatically from the silos and filled through Bates Bagging Machines into paper bags, which drop direct to conveyors which lead to Victorian Railways trucks, where it is loaded for delivery throughout the State.

The bagging machines are capable of handling 30 tons per hour each, with a full capacity of 800 tons per day.

At present the works are using 1600 tons of limestone per day to produce 15,000 bags of cement, which requires three tons of paper bags. The total consumption of water per day is 700 tons. Five hundred tons of steel balls are used yearly in the grinding mills.

All power for the works and quarry is generated in the company's own power station, where two of the largest turbines are installed. Two million electric units are generated monthly, and over 300 men are constantly employed.

Having personally conducted you through this tour of the Geelong works, which is typical of the plants producing cement by the wet or slurry process, may I, as briefly as I can, refer to the history of this industry in Australia, and again I must start at home, for, just about 50 years ago, and practically on the site of the present works at Geelong, cement was first manufactured in Australia. This new industry was controlled by some half-dozen Geelong and Melbourne builders and contractors, and worked with excellent results under the dry process, until 1910, when their interests were purchased by
"The Australian Portland Cement Co. Pty. Ltd." The old plant was demolished, and an up-to-date one erected and opened on 12th July, 1912, by the Hon. W. A. Watt, then Premier of Victoria. By 1917 the plant was producing over 1000 tons per week. As early as 1915, so efficient was the plant, its product was complying with the standard specification of the Engineering Standard Committee of Great Britain. Since then Geelong cement has complied with every world standard. So successful were the operations of the Geelong Company, that all other States have taken up the manufacture of cement, and can now more than supply the whole of the requirements of Australia.

What a romance the history of cement is, and how much the world owes to it. I have told you that it was not until about 1860 that any extensive use was made of Aspdin's great discovery, partly because of inferior quality, prejudice, and the vested interests of other cements, but primarily it was because the great march of the world's progress had not yet commenced. Wood, brick, iron, and natural stone were centuries old, and their uses for all structural purposes had been handed down through the ages and had always been sufficient for most requirements. Population, however, was increasing by leaps and bounds, and concentrating in towns and cities, necessitating greatly increased accommodation, larger dwellings, and public buildings.

James Watts's steam engine had made its first appearance, but only in 1785. George Stephenson saw it only in 1804 at Killingworth Colliery, and got his first idea of a locomotive, and by 1821, just three years before Aspdin's discovery, had produced one which drew coal dobbies at four miles per hour.

Internal combustion engines, turbines, steamers, and electricity have followed, so has massed production of goods, requiring heavy and constant running machinery, which necessitates massive foundations and structures. The colonies were developing fast and being peopled, demanding still greater production, transport, and storage. Both in the Old World as in the New water supply had to be provided and increased. Sanitation became imperative, old ideas and methods had to be scrapped, and new ones created to meet the advancing demands.

The whole face of the world changed. Cities sprang up in a night. Buildings grew from huts to skyscrapers. Barren wastes became luxuriant pastures, orchards, and vineyards. Road transport evolved from the old oxen and horse traction to our great commercial motors and Spirits of Progress. So
I might go on, but through all this change and during all this evolution there is not one avenue of development and advancement in which concrete and its greatest component "cement" has not played the leading part.

Can anyone, in these days of speed and bustle, roll back the years and actually visualise the evolution of the old pestle and mortar as a grinding agency, and compare them with the huge patent roller mills now producing man's greatest need, flour; or the spinning wheel and hand loom to the latest weaving machines producing millions of yards of clothing materials; or the 'primitive blacksmith shop to the immense steel mills, foundries, and engineering establishments responsible for the production of our steamers, trains, motors, airplanes, and armaments; or the humble single-storied dwelling of our forefathers to the great 120-story American skyscrapers of to-day, or again, and to stay nearer home, the old wooden trestle bridge to that magnificent Australian engineering achievement, the wonderful Sydney Harbour Bridge. So we could go on, but the gaps between these comparisons and dozens of others we could make are almost too immense to grasp, yet some of them have occurred within the lives of living people, within our own lives. I am not an old man, yet, but as a boy I spoke through the first Bell telephone installed in New Zealand. I rode on the first "push bike," and walked 10 miles to see the first one fitted with a free wheel. I worked the first "Brush" dynamo driven by a portable engine in Dunedin. I saw the first motor car in Melbourne, the first movie picture, the first aeroplane, and listened to the first wireless. And with very little stretch of imagination you could say that the advent of Portland Cement into our manufacturing spheres has contributed in the greatest possible measure to this advancement.

There is one comparison that strikes home to us in Victoria which I neglected to mention, that of an early map of Victoria describing the Mallee and portions of the Wimmera as "Australian Desert," while to-day's map shows it as the garden of Victoria, as undoubtedly it is. This was made possible by water conservation and irrigation, and these were only made possible in these areas by cement and concrete. How many of us actually have a knowledge of the water conservation of our State and how dependent we are on it. The Great Hume Reservoir, one of the largest in the world, impounding water in an area nearly four times greater than that of Sydney Harbour, and the Sugarloaf, Goulburn, Waranga, Yan Yean, Silvan, Maroondah, Pike's Creek, etc., all rely for their stability and safety on Portland Cement.
So it is that cement and its manufacture has become one of the greatest essentials in Australia’s national life, as it is one of the greatest romances in the world’s history.

Its possibilities are legion, and nowadays its use should be foolproof, as there are hundreds of textbooks, by prominent engineers, describing the various mixtures for different jobs, methods of testing aggregates for soundness and suitability, and quantities of water required, and as all Australian cements comply with standard specification, the most important factors for the securing of high quality concrete are careful selection and grading of both fine and coarse aggregates for the specific purposes for which the concrete is required, and also to secure a supply of good mixing water.

Any old sand will not do. Care must be taken in its choice. It is just as important to have high-grade sand as it is to have high-grade cement. It is also equally important to be sure that both the cement and sand are properly proportioned in the concrete mix. I would be safe in saying that in the majority of cases investigated into faulty concrete the cause can be attributed to bad sand, both for purity and grading. How often does one see, on a job, the same sand being used for heavy concrete as well as for plastering. Sand for concrete should be evenly graded from fine up to about 1⁄8 in., and be free from organic impurities. Coarse aggregate should consist of screenings, crushed from hard stone or clean gravel. Both should be free of fines or dust, as these interfere with the correct gauging of the sand to go into a mix, as it is difficult to estimate the quantities of fines contained in screenings or gravel, when delivered in bulk. The grading for screenings or gravel varies for different jobs, but for such work as footpaths, floors, and thin walls, the grading should be within the limits of 1⁄4 in. up to 3⁄8 in. For roads, heavy duty floors, foundations, and thick walls, the limits could be within 3⁄8 in. to 1 in. For mass concrete the upper limit could be slightly higher, and plums or spalls could be embodied in the mass, while the mixture is being placed.

The quantities of aggregates in concrete mixes and the amount of water required also vary considerably for different jobs, and each one should be considered independently, there being no hard and fast rule. One great axiom should always be followed: “Use as little water as possible to get a plastic workable mixture, and avoid a sloppy mix at all costs.”

Gentlemen, this concludes my little talk, and I hope that what I have had to say has been of interest to you. Before sitting down, however, I just wish to state that the Cement Manufacturers Association of Australia has had pamphlets
DISCUSSION

After the paper had been concluded, a general discussion took place, in which Messrs. Pyke, Trewhella, Kneale, and others took part.

In reply, Mr. Bremner dealt with the various points raised. As the very fine particles of cement are the only binding agents in concrete, it was essential to so arrange the mix that a voidless mass was obtained if best results were desired. The use of more water than was actually necessary to thoroughly mix the ingredients only resulted in voids, and therefore weakness. As the mixing of concrete caused vigorous chemical action with heat and expansion, due allowance should be made for this, and also for the inevitable cooling and contraction. The mixing of too large a batch at a time had caused enormous fissures in a recently-constructed dam in U.S.A. It should be remembered that cooling and contraction often continue for 30 days. As the initial set took place within 70 to 90 minutes, mixed concrete should be in its final position well before that time after mixing. Complaints about quick-setting cement were always traceable to the time factor having been ignored. If cement was required for high temperature work, on no account should sand be used. In its place ground clinker was recommended.