How Concrete Started—Part 1: Sun Dried Brick

10/14/2020

Part one of a six - part series on the origins of concrete.

I set out on a quest to learn when and how concrete got its start. After reading several books and reviewing research reports and internet blogs, it became apparent that the starting point of concrete hinges on how you define concrete. Thus we must first define two terms we use today, sometimes (incorrectly) interchangeably. Merriam-Webster defines:

- Concrete as “a mass formed by concretion or coalescence of separate particles of matter in one body.”
- Cement as “a substance to make objects adhere to each other.”

Although these definitions are rather vague, they give us a starting point. One of the earliest methods of creating a concrete would be construction using sun dried bricks. To make the construction stable they used mud as a cement and plastered the entire wall with mud to give it a smooth finish.
Today we would call this construction style masonry, however it does meet the above definitions of concrete and cement and may be the genesis of today’s concrete.

Sun-Dried Brick

Archeologist have found evidence of sun-dried brick structures in Jericho dating to 9000 BC. These bricks are made from clay and reinforced with straw. The technique of making these bricks was quite simple. Clay, water, and straw was mixed to form a slurry. This slurry was then cast into forms or hand-shaped into bricks and left in the sun to dry. The straw was a reinforcement that kept the bricks from cracking while they were drying.

During the drying time, the bricks needed to be turned to achieve uniform drying. Typically, the drying process takes 2 to 3 weeks. The mortar used to hold the bricks together was also clay mud as shown below.

Building a wall with sun dried brick and mud mortar.

Sun dried bricks have played key roles in the history of several religions. The biblical story of Exodus starts with the Jews in Egypt being forced to make sun-dried bricks. As punishment for asking for time off to celebrate a religious holiday, the Pharaoh demanded they also gather the straw needed to make the bricks. Previously other people had gathered the straw and provided it to the brick makers. Now the Jews had to also gather the straw plus maintain the same production quota. This extra work set the stage for intense negotiations between Moses and Pharaoh ultimately resulting in the exodus from Egypt. For more detail, see Exodus, Chapter 5.

As Islam developed in northern Africa, mosques were built. These were in the desert and needed to use local building materials—mostly sun-dried bricks.The great Mosque at Djenné, built in Mali in 1120 was rebuilt in 1907. This mosque hold over 3,000 worshipers and is believed to be the largest building ever constructed with sun-dried brick and mud mortar. Since Mali has a rainy season, the mosque requires routine maintenance to replace any clay that washes away. Thousands of Djenne residents participate each year in the plastering ceremony of the Grand Mosque, which will now be powered by solar electricity.

The Great Mosque of Djenne.

In North America, Casa Grande was built in the Arizona desert around 1300. It was an elaborate settlement with a main building, irrigation canals, housing, and a sports field. Although it was not built with sun dried bricks, it was built using mud (called caliche or hard pan). The caliche was mixed with water and placed by baskets. The sun-dried caliche mixture resulted in a type of concrete structure. This method of mixing the caliche, placing it into the structure, and letting it harden is much like modern day concrete construction.

Casa Grande with its protective cover in place.

No one is sure of the purpose of this structure. It appears to have been built to celebrate the summer and winter solstices so was likely part of religious ceremonies. Casa Grande was abandoned around 1450 so little is known about the builders or it purpose. It is now a national monument with a roof installed overhead to protect it from the weather.

But the main use of sun-dried bricks, historically and still today, is for housing. Homes made with sun dried brick help moderate the interior temperature. During the day the heat slowly increases. During the cool nights, the heat will slowly be released thus providing a relatively comfortable living space in hot, dry areas.

Ruins of mud-dried brick homes in Saudi Arabia.

Sun dried bricks worked well in very dry areas however they were problematic in areas that received much rain. Our ancestors saw the need to improve the sun-dried brick and the mortar that holds them together.

The next steps required toughing the bricks so they were more durable and stronger plus developing better bonding materials to hold the bricks together in any type of weather. We'll cover that in Part Two

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The Tower of Babel by Pieter Bruegel the Elder, built with fired brick.

How Concrete Started—Part 2: Fired Brick

10/27/2020

In my quest to learn the origins of concrete, I choose as a starting point the sun-dried brick with mud as its cement or binder. But sun-dried bricks were not very strong or durable, thus our ancestors began a search to improve the brick. The improvement appears to have been inspired by the development of pottery, which also eventually led to the discovery of new cements.

Archeologist tell us that Homo Sapiens figured out how to make and control fire about 125,000 years ago. This was a major milestone in man's development. With fire they had the means to cook food, keep warm in cool weather, security from wild animals and insects, and a place for social interaction. We are still drawn to campfires where we sit staring into the flames, share food, sing songs, tell stories, and pass onto younger generations traditions from our past.

Campfires are not extremely hot with temperatures around 1000 F. Someone got the idea that they could harden clay by using the heat of the campfire and begin experimenting with this new technology. As a result, around 29,000 years ago people in Central Europe made a clay figurine and put it in a campfire. Archeologist have determined that the Venus of Dolce Věstonice it was fired at about 800 F (well within the temperature of a campfire).

The Venus of Dolce Věstonice

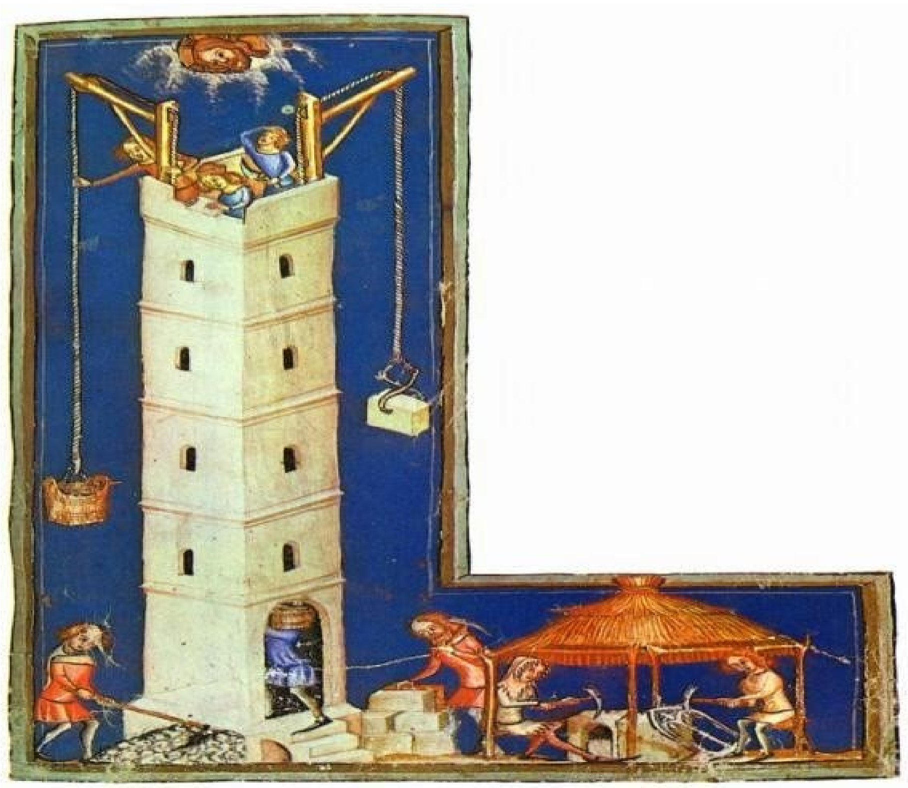
This figurine is the oldest artifact in which clay had been fired. Thus we can conclude that the process of using heat to improve an object made of clay was understood or was in development by 29,000 years ago.

Pottery artifacts using this same technique were found in China, dating to 20,000 years ago. This fired clay pottery provided better containers for storage of food and liquids and represented a major step in finding new applications for this advancing technology. The technology of making fired clay pottery appears to have spread slowly. Archeologist have found fired clay pottery in Japan and Russia from 16,000 years ago and in the Middle East from 11,000 years ago.

Oldest fired clay pottery - found in China

Applying this technology to make a better brick first appears in China around 6400 years ago. These bricks were fired at about 600 F (easily achieved by a campfire). These bricks were used as a flooring material for houses.

The Bible (Genesis, Chapter 11) mentions using fired brick in the construction of the Tower of Babel. Biblical scholars estimate that this event occurred about 2200 B.C. ago in the Middle East. Various dates are attributed to when this account was written varying from 1300 B.C. to 500 B.C. The builders that attempted to build this tower must have understood that mud bricks were not strong enough for the planned tower so they decided to make and use fired bricks. Thus we know that the technology of making fired bricks was understood at least by the time of the event was recorded. The tower was never completed but it did become a popular topic of religious painters.



The Tower of Babel as envisioned by a late German Medieval painter around 1370 A.D..

The Biblical account also introduces the use of tar as a mortar. Since there were several tar pits mentioned in the Bible in this general area (Genesis chapter 14, verse 10), tar appears to be a logical material for them to have used.

Tar would have been relatively abundant and easy to collect. Tar was superior to mud as a mortar, however its use was limited to areas that had tar pits. It would also have been rather unsightly and so thankfully this technique never caught on.

In the next two articles in this series, we will discuss theories of how new and improved cements were discovered and how this discovery resulted from the campfire and attempts to make improved pottery.

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How Concrete Started—Part 3: Gypsum

TAGS: MATERIALS CONCRETE: SLABS, STRUCTURAL, PAVING MASONRY

In Part Three of this six-part series, concrete historian Luke Snell takes us another step closer to the development of modern cement with the theory that the first man made cement was gypsum.

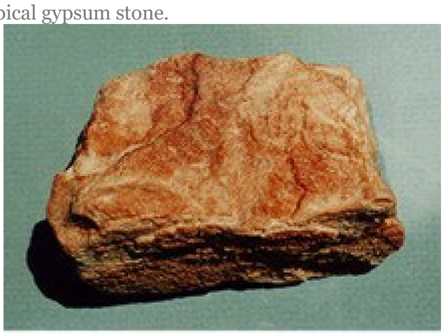
Luke Snell | Nov 23, 2020

In the first two articles, we explored the first two cements or mortars used (mud and tar) and the first two masonry units (sun-dried brick and fired brick). In this article we investigate the likely accidental discovery of powdered gypsum used as mortar, although its potential use was not realized until centuries later.

To contain fires, early man likely built fire rings with stones. They would have witnessed the devastation caused by forest fires, uncontrolled fires, and campfires that were not properly contained. They knew this was a necessary step as they learned how to control and use fire safely.

Some of the stones used to make a fire ring would likely be gypsum. Gypsum is a common sedimentary rock formed from ancient oceans. It is in thick layers and can be found at or near the earth's surface.

Typical gypsum stone.



Chemically, gypsum is a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$. Early man may have used gypsum because it was soft and could be easily carved. Some of the lower quality gypsum rocks that they did not use for carving would likely have ended in fire circles.

At temperatures around 300 F, well within the range of a campfire, part of the water is driven off from the gypsum molecule:

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot 1.5\ H_2O + 0.5\ H_2O$$

The water is released as steam and the gypsum turns into a dry powder. When that dry powder comes in contact with water, it becomes a mortar and that will ultimately revert back to gypsum. This process is quick, the mortar sets in just a few minutes and provides a weak bond that can hold blocks, stones, or aggregates together.

Since 300 F is easily achieved in the stones of a fire ring, logically some parts of the gypsum rocks would have water driven off and the above chemical reaction would have occurred. If this was followed by exposure to water (either rain or water used to put out the fire), they would have witnessed the first man made cement.

By taking small gypsum rocks, they could easily repeat this process and be able to recreate this cement. Some of the first uses of this material were likely as a coating of walls (plaster) and mortar for sun dried bricks. Early men could have also made useful household products or figurines with it.

Products made with this new gypsum powder were not very strong or durable. When in contact with water, it loses strength and breaks rather easily. For these reasons, archeologist have not found any evidence of mankind using gypsum until the construction of the pyramids.

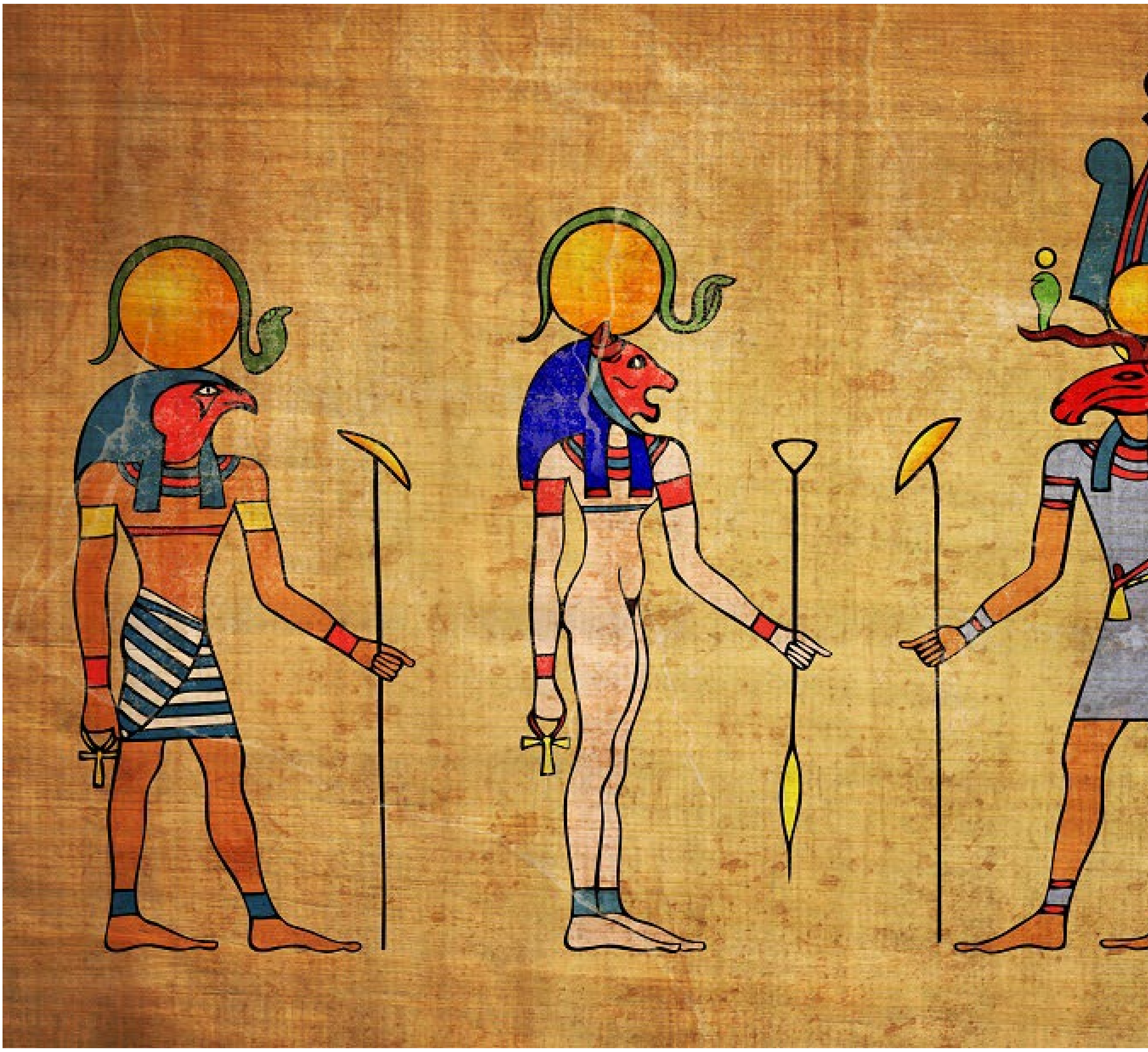
Egyptians used gypsum as a mortar and as a plaster while building the pyramids in 2600 B.C. Egyptologist suggest that pyramid builders did not need mortar to hold the massive stone blocks together since they were cut so that the gaps were less than 0.02 inches and gravity would hold the blocks together. It was speculated that the use of the gypsum mortar was because there was an abundance of gypsum in the area and that the gypsum mortar would “butter” the joints and make it easier to push the blocks into place. At this time in history, few tools had been developed, thus these blocks having an average weight of 2.5 tons had to put into place by brute force. By buttering the joints, it was thought it would be much easier to push these blocks into place.

This photo of the pyramids at Giza taken in 1858 shows the white gypsum mortar between the blocks.

The mortar used for construction of the Egyptian pyramids was analyzed in the 1920s and found to be gypsum with small amounts of limestone and sand. The gypsum rocks in this area of Egypt have about the same percent of sand and limestone, so it was logical that the gypsum mortar was processed from the local gypsum rocks.

In a simple laboratory experiment using concrete bricks, the force of moving a brick was reduced by over 50% when the sliding surface was "buttered" or had a fresh gypsum mortar between the bricks. The speculation that buttering the joints of large rock masonry units to ease construction appears to be reasonable.

Egyptians also used the gypsum as a plaster on the interior walls of the pyramids. It provided smooth writing or drawing surfaces that has lasted over 4600 years.



Egyptian paintings inside one of the pyramids on a gypsum plastered wall.

Early man learned there were two problems with gypsum cement. It was not particularly strong. And when wet, it would lose strength entirely and easily break. Another problem with gypsum is its short pot-life. It sets in just a few minutes (my experience is that plaster starts to set in 10 to 15 minutes). This does not allow much time to work with the mortar during construction.

When using this gypsum for interior work, such as the pyramid walls where there is virtually no moisture, setting times doesn't pose a problem. It bonds well to the walls and provides the needed smooth surface for writing or painting.

When used to butter the joints between blocks, gypsum must be applied just before the final placement of the blocks. This provides the lubricant needed for the few minutes needed to move the block into place.

This gypsum cement probably had limited use at the time of its discovery. Using mud as a mortar was quite effective and required less preparation.Gypsum used as a plaster did not become common until the late middle ages. Because it could easily be shaped and carved when set, it was used to decorate many important buildings such as palaces and churches. Today gypsum is widely used as wall boards in most residential construction. Most of us have probably made crafts or molds with plaster of paris, a very pure form of gypsum cement.

Although gypsum may have found limited use when discovered, it reinforces the idea that we can use heat to transform clay or stone into useful products.

In the next article we will discuss how our ancestors continued their search for better and more robust cement.

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How Concrete Started—Part 4: Lime

TAGS: MATERIALS CONCRETE: SLABS, STRUCTURAL, PAVING MASONRY

Limestone rocks were turned into mortar.

In Part Four of this six-part series, concrete historian Luke Snell looks at the many steps involved in lime production and speculates on how it may have been discovered.

Luke Snell | Dec 08, 2020

Concrete historians have speculated that the first cement (one that is similar to modern portland cement) was lime. This conclusion is based on that the production of both materials is similar and both materials use limestone as a basic ingredient.

Archeologist have found evidence of lime being used as a cement in what is today Turkey and Israel from about 7000 BC. This ancient lime cement closely resembles modern day concrete. Thus, we need to look at the many steps involved in lime production and speculate how these steps may have been discovered.

To make lime from limestone (calcium carbonate, $CaCO_3$) is a simple chemical formula but a relatively complex process that requires many steps. First, the limestone is heated to higher than 1650°F resulting in the following reaction:

$CaCO_3 \rightarrow CaO + CO_2$

The carbon dioxide (CO_2) is released as a gas leaving calcium oxide (CaO also called quicklime), which is not stable. L on its own, quicklime will react with the CO_2 in the air and revert back to the limestone (calcium carbonate). If it is protected from the air and has water available, it can become a lime mortar as shown below:

$CaO + H_2O \rightarrow Ca(OH)_2 +$ heat

This process is called slaking and can take a considerable amount of time. In the United States, one of the early ways of slaking was to put the quicklime in a hole in the ground to protect it from CO_2 and let the moisture from the soil react with it.

This slaked lime ($Ca\ (OH)_2$ or calcium hydroxide) is very caustic and the reaction with water is violent, therefore making it in the ground eliminated many of the problems of handling the material during the slaking process. Once the slaking process is complete, what is left is lime putty that can be used as a mortar. One of the ways people knew this process was complete was to stick a trowel into the mixture. If nothing stuck to the trowel the process of slaking was considered complete. The mortar then could be placed between stones or bricks to join them together or if mixed with aggregates to make a simple concrete. The chemical reaction is:

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3$

When the mortar reacts with carbon dioxide in the air, the limestone cycle is complete, and limestone has been re-created. Now, however it is the cement that holds the bricks, stones, or aggregate together into a solid mass. Archeologist have found evidence of lime being used to make concrete floors in 7000 BC. We can conclude that they must have understood the process by this time and knew how to mass produce lime putty and mortar.

One of the main difficulties our ancestors faced was how to get enough heat to start the process. Again without written records, we can only speculate on how they developed a process of getting the needed high temperatures (above 1650°F) to create quicklime. In article three of this series, we noted that a campfire only gets to about 1000°F, a temperature well below what was needed to make quicklime. Article 3 also showed that they knew how to fire clay to make figurines and pottery at least 5 to 10 centuries before the first known use of lime.

Our ancestors must have learned by experience while making and firing figurines and pottery that hotter fires gave them better and more durable figurines or pottery. Thus began their quest of discovering methods to get higher temperatures.

To better understand the steps in getting higher temperatures, we need to trace some of the major developments of man. Archaeologists tells us that the discovery of how to make and control fire occurred by at least 125,000 BC, but there is no agreement on the exact date. In this article, I am taking a conservative approach and use dates that have the most consensus.

These ancient fires were most likely wood fires except in areas where trees were scare, where dung was used as fuel. Dung is still used in some countries today. In rural Mongolia, dung is collected from sheep and goats each morning with a dung catcher. In other areas of the world, this is done by hand.

Gathering and drying dung in Mongolia to use as fuel.

The dung is then dried and stored for heating and cooking fires. In some developing countries this remains a major fuel source. In the American west in the 1800s, settlers did the same thing, collecting "buffalo chips" using them for fuel.

The smoke from dung fires can cause severe health problems and many health agencies have worked to help people using dung for cooking and heating to find alternative fuel sources. Dung is free and available so for those in poverty, the practice continues.

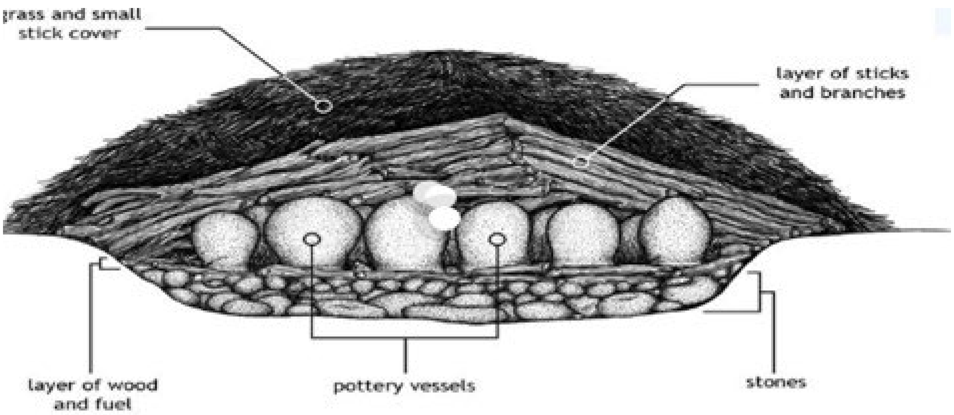
The first attempts at making clay figurines or pottery could be achieved at temperatures consistent with a wood or dung fire. The clay would be formed into the figurine or pottery and then covered with wood or dung. The wood or dung was set on fire and the clay was fired. For those interested in more details on this process, there are several YouTube videos on how to make pottery with open fires using this technique.

People living in areas where wood was scarce learned that dung fires were superior to wood fires, providing uniform heat that resulted in less breakage during the firing process. Modern researchers using infrared thermometers have found that sheep dung (thought to be the first domesticated animal) provides the highest temperature fires compared to other animal dung.

Modern day experiments using dung fires to make pottery.

Those making pottery in ancient times could not measure the temperature but through trial and error they were able to evaluate the effectiveness of each fuel they tried. The pottery made using sheep dung had less breakage while in the fire and produced a much stronger and more durable pottery than those achieved using other fuels. They would realize that the hottest fires provided the best results, so they began searching for ways of getting even higher temperatures.

A likely scenario was that they realized that a lot of heat was lost in an open fire, resulting in the idea of confining the fires and trapping the heat. This resulted in the development of kilns.



A native Native American kiln.

This drawing shows small rocks below the pottery. If these rocks were limestone, a very common rock, the fire would have converted some of the smaller pieces to quicklime because the temperatures at the bottom of the kiln would now exceed 1650°F.

After experimenting with this powder (and getting burned a few times because the quicklime reacted violently with the moisture on their skin), they learned how to handle it and ultimately make lime mortar.

Here are the steps in this process and an estimate of the amount of time involved to mass produce lime in 7000 BC (the 1st known use of lime):

1. Limestone rocks would need to be reduced in size to 1 to 2.5 inches. This would probably take several days and they would probably have used stronger rocks as hammers.

1.Place the limestone rocks with fuel into the kiln; this would take about 1 day.

2. Heat the limestone in the kiln for 3 to 7 days. They would need to maintain the temperatures above 1650°F by adding more fuel as needed. The kiln would require constant supervision. This process would require a lot of fuel. Note: The first kilns existed before there were steel axes, so if they were using wood as fuel, gathering the necessary amount of wood would be a challenge in itself. Using dung, peat, or coal as fuel would also create a challenge in gathering the needed amount.

3.The quicklime this process created would need to cool and then the kiln could be unloaded. This would take about 1 additional day and it would be dirty, dangerous, and difficult work.

4. Next the quicklime had to be protected from the air and exposed to water to complete the slaking process. This could take days to complete.

5. The resultant lime putty was now ready to use as a mortar or as a cement.

The process would likely have evolved over several centuries because of the multiple steps that had to be mastered to complete the process. Ultimately, with great perseverance, our early ancestors were able to perfect the process for making lime mortar.

In our next article, I will finalize my quest of when concrete started and then in Part 6 we will look at how the Romans took cement to a whole new level.

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How Concrete Started—Part 5: Roman Concrete

TAGS: CONCRETE: SLABS, STRUCTURAL, PAVING

In Part Five of this six-part series, concrete historian Luke Snell looks at the accomplishments of the Romans in discovering how to mass produce quality concrete.

Luke Snell | Dec 21, 2020

When we think of the start of concrete we are immediately drawn to Rome. Some of the concrete structures in Rome have survived for two centuries while our modern concrete structures often show distress in their first 50 years. We are in awe of how they mastered the art of making durable concrete. In this article, we will look at some of the contributions to concrete by Roman engineers and some of the ways they made quality concrete.

By the time of the Roman Empire began (27 BC), the use of lime as a cement was well established. With the Pax Romana (Roman Peace) that lasted for the next 200 years, engineers turned from military activities to civil projects. Thus, began the great development of concrete and a building boom across the Roman empire.

Rome being the center of the Empire attracted many of the outstanding engineers and craftsman of the time. Rome was the place to be, it's where things were happening. The best wanted to be part of the building boom thus this great talent was able to bring innovation and development of new construction techniques.

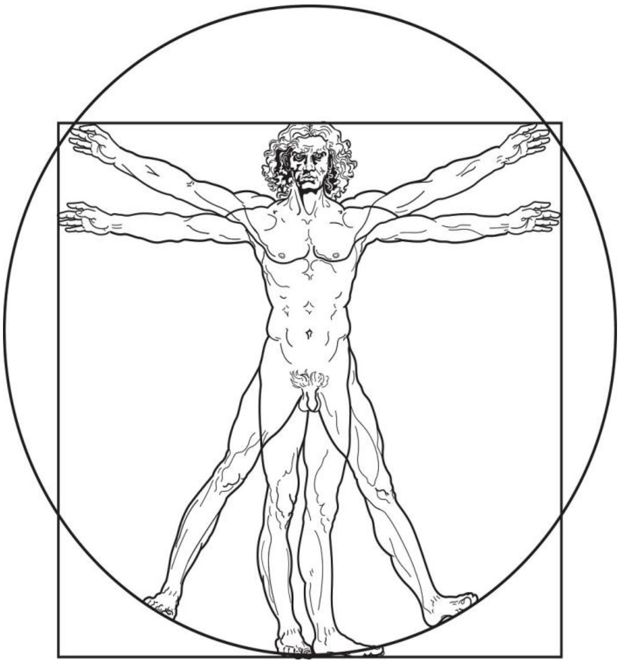
Bas-relief of an ancient Roman farmer throwing seeds on the ground in the the public Baths of Diocletian in Rome, built from 298 to 306.

Cato

One of the first writers to document this innovation in concrete was Cato in his book De agri cultura (On Farming). He stressed that to make good lime required good quality control and detailed how to accomplish that. He stressed using only good limestone (white and uniform as possible), uniform heat both day and night, along with other procedures. He also provided detailed instruction of how to make a kiln so as to maximize production. Cato followed the same procedures to make lime that were discussed in the Part 4 of this series, with emphasis on improvements that allowed mass production.

Cato recommended a concrete mixture of two parts sand to one part lime. One concrete historian speculates that his quality control standards for making lime was not extended to the sand used to make the mortar or concrete. It appears that he willingly used low grade sand with clay and silt probably because it was cheap or available on his farm.

This resulted in a mixture with high amounts of the more expensive lime. Cato was very frugal so this is surprising. His contributions to making quality lime should be recognized however and we need to forgive him for not seeing the whole picture of how to make an economical, quality concrete.



Leonardo's Vetruvian Man was based on the philosophy of Virtuvius.

Vitruvius

After Cato, much of the development of lime and concrete was documented by Vitruvius in his book De architectura (On Architecture). This book covered many aspects of engineering, architecture, construction, and life in general. Vitruvius started his career in the military but because of the Pax Romana was able to apply his talent to civil projects. Thankfully, he was also a writer and documented the state of engineering and construction.

Two of the major developments Vitruvius described that relate to concrete are the use of volcanic ash as a pozzolan and the necessary quality of sand.

Pozzolans

Addition of pozzolans (volcanic ash) to concrete: We now know that pozzolans react with calcium hydroxide and create a cement. Although they didn't understand the chemistry, they realized that mixing the pozzolans with the lime gave them a better concrete. Vitruvius wrote that "pozzolans mixed with lime and clay bricks cannot only be used in buildings but also for strengthening of structures in the sea, because suddenly it hardens and it can even harden submerged in water."

This was a major accomplishment. Lime by itself will not set under water (it needs carbon dioxide from the air to set or harden). With the addition of the pozzolans they were able to produce a hydraulic cement that would set under water. It should be noted that not all volcanic ashes react with lime, however the volcanoes near Rome had the right chemistry and made a very durable concrete.

Roman engineers were able to use this technology to build concrete docks and complete harbors; some of this concrete still exists today. It wasn't until the 20th Century that pozzolan (fly ash) was again used in concrete. Now it is routinely added to most concrete mixtures.

Sand quality

Cato may have had little regard for the quality of the sand he used in his concrete, but Vitruvius took a different approach seeing that good concrete required good quality control of all the materials including the sand.

He wrote that one should not use river or sea sand to make concrete because it is smooth. He recommended using pit sand with its angular edges. We now know that smooth sand will not bond as well with cement and will result in lower concrete strength. The angular sand gives more bonding surfaces for the cement resulting in a stronger concrete.

He also described a test to determine if the sand was acceptable for use. The sand was thrown onto a white cloth. If the sand did not stains the cloth, it would be considered acceptable and could be used in concrete. This test was to determine if organics, silt, or clay were in the sand. We run similar tests today however they are a bit more sophisticated.

Blood

Two other major improvements to concrete that were developed by Roman engineers were the addition of animal blood and the development of lightweight concrete.

No one has a definite idea of why someone thought that adding blood to the concrete was a good thing. Maybe they were looking for ways to dispose of waste blood from the slaughterhouses and someone thought to put it into the concrete. When I was a professor, I would routinely get calls from companies asking if their waste products could be used in concrete. They were not interested in improving concrete, they just wanted to get rid of their waste. This is a possible scenario in Roman times as well.

It was not until the 20th century that we realized that the blood was creating small air voids (entrained air) that protected the concrete from freeze-thaw issues. Today's concrete still uses this same concept. We add chemicals (admixtures) to concrete to create entrained air to resist freeze-thaw damage; thankfully we no longer use blood.

Although there are many references that the Roman engineers added blood to the concrete, I doubt it was widely done. Too much blood would cause excess entrapped air in the concrete that would weaken the concrete. Thus, the amount of blood would need to be carefully controlled and added to the concrete in small amounts.

Lightweight Concrete

The Pantheon is one of the most remarkable structures to use Roman concrete. To this day, we are unsure how this structure was built, but we do know that part of its success was the use of lightweight concrete in building the dome. A building must be designed to hold all expected loads plus the weight of the building materials (dead load). By using lightweight aggregate, the weight of the concrete is significantly reduced and the engineer has less load to contend with.

Near Rome there was a lot of lightweight aggregate available around the volcanoes. Using these aggregates could reduce the weight of the concrete by up to one-third and allow for a lighter structure with graceful lines and appearance.

I have touched on only a few of the many accomplishments Roman engineers had using concrete. They advanced our knowledge of concrete and became the first to mass produce durable concrete. Unfortunately, with the fall of the Roman Empire (476 AD), much of this concrete technology was lost. For the next 1000 years the basic idea of making and using lime survived with little advancement in concrete. In the 15th century a monk (Giocondo) in Switzerland found in a monastery library the writings of Vitruvius. It makes you wonder how a manuscript found its way from Rome to a monastery in Switzerland and somehow survived for over 1000 years.

Again, by good luck, Giocondo was both a scholar of Latin and engineering, thus he recognized the significance of what he had found. He translated the books of Vitruvius and allowed us to reclaimed the advancements that the Roman engineers had discovered about making concrete.

The Abbey Cathedral of Saint Gall where Vetruvius's manuscripts were rediscovered.

The next and final article in this series will summarize how concrete got its start.

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How Concrete Started—Conclusion: Timeline and Observation

By Luke M Snell

TAGS: CONCRETE: SLABS, STRUCTURAL, PAVING MASONRY

Modern concrete emerged from a series of human technological advancements.

In Part Six of this six-part series, concrete historian Luke Snell reviews all of the historical advancements that led to modern concrete.

Luke Snell | Jan 12, 2021

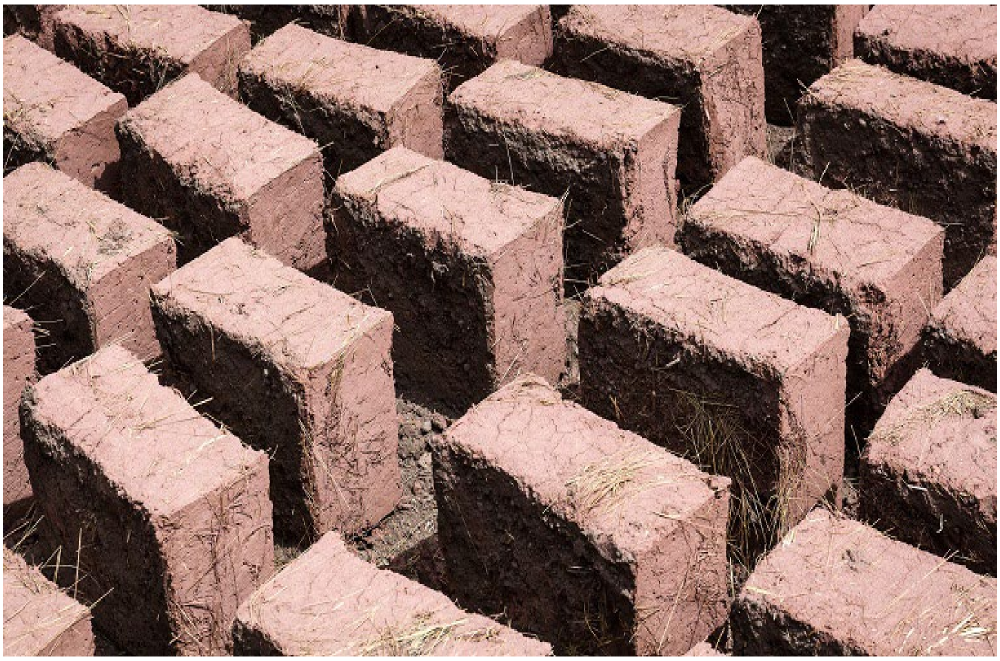
When I began this quest to learn when and how concrete started, I thought I had the answer. All I had to do was put it in writing so others could see my logic and conclusions. But the more I researched the first steps of making concrete, the more I realized that it is more complex than I thought. The start of concrete really depends on your definition of concrete.

Hopefully, as you have followed this series of articles you have developed some opinions on how concrete got its started. It might be helpful to review a timeline of some of the important dates and details that we have discussed in the previous articles. The dates are provided by archeologists and will be updated and possibly changed as more information about our past is discovered.

Timeline

1. Widespread control and use of fire by man: 126,000 BC
2. Making fired clay figurines (Czech Republic): 29,000 BC
3. Making fired clay pottery (China): 18,000 BC
4. Making sun dried bricks (Israel): 9000 BC
5. Making lime (Turkey and Israel): 7000 BC
6. Making fired bricks (China): 4400 BC
7. Making gypsum (Egypt): 2600 BC
8. Making Roman cement (Italy): 1 AD

There are several discoveries we considered as the start of concrete. Each is a potential starting point for concrete, and each will have it doubters.



Sun-dried bricks.

Sun dried bricks with mud mortar (Part 1): This meets the definition of both cement and concrete and it has been in use since at least 9000 BC. Because of the simplicity of this construction, it was likely used much earlier. Unfortunately, this type of construction was not durable so earlier dates of its use are unlikely to be found. Some readers will complain that sun dried bricks and mud mortars are very different than today's concrete, so this is not an acceptable starting point. They might accept this as a starting point for masonry, but not for concrete.

The Tower of Babel by Pieter Bruegel the Elder, built with fired brick.

Fired bricks with various mortars (Part 2): This again meets the definition of both cement and concrete and it has been in use since at least 4400 BC. The same readers that complain about sun dried bricks and mud mortars will also find this is not an acceptable starting point. They will agree this was a major step in masonry and construction but not for concrete. The Biblical story of Tower of Babel indicates that fired bricks may be much older than the fired bricks found in China. Their use of tar (asphalt) as a mortar was one of the many reasons why this construction was unsuccessful. Thankfully this poor choice of mortar did not stop the advancement of masonry and concrete.

Gypsum cement as mortar and plaster (Part 3): There is no record of when gypsum cement was discovered. In Part 3, I discussed how a campfire could have led to the discovery of gypsum as a cement. If this is true, then gypsum cement could have been discovered as early as 125,000 BC right after our ancestors learned how to make and control fire. This could have led to attempts to use this new cement to create a concrete. Thus this would be the first cement created using heat, similar to how we make cement today. Some readers will point out that the first known use of gypsum was in the pyramids in 2600 BC. The Egyptians used the gypsum as a method to ease construction by buttering the joints so they could maneuver the huge stone blocks into place. The gypsum was not intended to be a mortar or a cement to hold the blocks together and thus one could argue that this does not fit the definition of a cement.

The other use of gypsum at around the same time was as a plaster to create a smooth surface for writing and painting. Since this usage of gypsum was as a covering of a wall, it again does not meet the definition of a cement. This argument is further strengthened by the fact that no gypsum concrete artifacts have been found earlier than 2600 BC. Even if the discovery of gypsum cement was as early as 125,000 BC, we have no records that it was used prior to construction of the Pyramids.

Limestone rocks were turned into lime mortar.

Lime (Part 4): The process of making lime appears to have been well understood by 7000 BC. In my opinion, the knowledge our ancestors had accumulated by then allowed them to make the leap to producing lime. This is what they knew at that point:

1. Cementitious material could be made from gypsum rock using the heat of a normal campfire.
2. Heating or firing clay resulted in more durable figurines and pottery than could be achieved with sun-dried clay.
3. Higher temperatures resulted in superior clay products, leading to a search for how to achieve hotter fires.
4. Quicklime could be produced from limestone (a very common rock) when it was used to line the kiln while making pottery.

Some concrete historians have suggested that the manufacture of lime preceded the making of pottery since pottery was not found in some of the earliest sites that had used lime to make concrete. Since the firing of clay to make a figurine was at least 20,000 years before the first evidence of the manufacture of lime, it is possible that the knowledge of how to make lime spread more quickly than the making of pottery.

The Pantheon built with Roman Concrete in 27 BC survives today.

Roman Concrete (Part 5): Roman engineers appear to have captured all of the earlier developments of making lime and concrete. With about 200 years of peace, they had their engineers turn their attention to civil projects rather than military activities. This resulted in several great advances in how we make and use concrete. The many Roman concrete structures that survive today is a testament to their advancement in concrete technology. Some people will say that the Romans were the first to truly understand and use concrete. Their advancements in using air entrancement (animal blood), pozzolans, and lightweight aggregate could be considered the first concrete since it is similar to the way we make concrete today. Some will say that the Romans were just building on past successes and their accomplishment were the logical next steps in the evolution of concrete. They will agree that Rome had many accomplishments in concrete technology, however concrete was developed well before they made their improvements.

All of this led directly to the discovery of modern portland cement and the concrete of today. Key steps in this development were:

1. John Smeaton (1750) found that adding clay to the manufacture of lime resulted in an improved cement. One of his major accomplishment was to build the Eddystone Lighthouse using this new cement.

2. Joseph Aspdin (1824) obtained the first patent to make “portland cement” by increasing the temperature and controlling the addition of clay.

Some readers will argue that concrete really started with the Romans, John Smeaton, or Joseph Aspdin since their cements and resultant concrete is closest to modern concrete. I don’t disagree with this opinion.

I thought I had the answer before I started on this quest. But the more I researched this, the more I realized that concrete was not a single discovery but a series of discoveries that happened all over the world. Which theory of when concrete likely started one adheres to depends on both your definition of concrete and what you think was the most important or key first step. Regardless of which theory you like about the start of concrete, we can be thankful to our ancestors that they kept at it to develop the concrete we have today.

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