JOURNAL OF CONSTRUCTION AND BUILT ENVIRONMENT
VOL 3, DEC 2023,
ISSN (PRINT):2709-1449 ISSN (ONLINE): 2709-1457.

RESEARCH ARTICLE

Exploratory study of calcium silicate bricks as a potential material for building construction

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Abstract: Bricksare a common building material used for construction due to its strength and longevity. Rapid urbanization and rising cost of building materials has led to the increase demand for brick as filler material in the building industry. Conventional burnt brick puts tremendous pressure on the environment since the burning process results in the production of greenhouse gases. In recent times, the attention has been turned to sustainable and eco-friendly building materials. However, alternatives such as hollow concrete/calcium silicate blocks are now available, which are a bit costly as compared to burnt clay bricks. The calcium silicate brick consists of natural raw materials such as sand, quicklime and water. The Calcium silicate bricks allow natural, energy-efficient, eco-friendly, and agricultural-friendly building materials for sustainable development. Architects often prescribe sand-lime bricks for a building project, because of the bricks' good acoustic insulation, good heat and humidity absorption, as well as excellent fire resistance.This paper examines the case of calcium silicate bricks as filler material and analyses the engineering viability and properties of such brick in building construction. The paper concludes that calcium silicate bricks are a viable alternative to conventional bricks with more intangible benefits attached to them.

Keywords: Calcium silicate bricks; Sustainable building materials; Construction; Developing countries

1 Introduction

The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the

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planet, and ensure that by 2030 all people enjoy peace and prosperity. The Goal 9 targets to build resilient infrastructure, promote sustainable industrialization and foster innovation. A functioning and resilient infrastructure is the foundation of every successful community. To meet future challenges, our industries and infrastructure must be upgraded. For this, we need to promote innovative sustainable technologies and ensure equal and universal access to information and financial markets (UNDP, 2023). This will bring prosperity, create jobs and make sure that we build stable and prosperous societies and communities across the globe. In this regards, low energy, eco-friendly sustainable building materials are required for the infrastructure development (Kamal, 2016). The Calcium silicate bricks are natural, energy-efficient, eco-friendly, and agricultural-friendly building materials for sustainable development. Calcium silicate bricks are made of sand and lime and are popularly known as sand-lime bricks. These bricks are used for several purposes in construction industries such as ornamental works in buildings, masonry works among others. Sand lime bricks are popularly used in European countries, Australia, and African countries. In India, these bricks are widely used in Kerala state and their usage is regularly growing. Calcium silicate bricks are suitable for use in both external and protected internal walling. They are available as facing bricks or as commons. As for clay bricks, they are available in a solid or a frogged unit and are made to a standard size of 216 x 102.5 x 65 mm. The method of manufacture together with inherent properties of the mixed raw materials produces a brick with fine dimensional tolerances and good clean arises. Figure 1 shows the colored Calcium Silicate or Sand Lime Bricks (Adlakha, 2019).

Figure 1: The colored Calcium Silicate or Sand Lime Bricks

2 Raw Materials Used for Sand Lime Bricks

The raw materials used in the manufacture are a very fine siliceous aggregate, high calcium lime, and water. Inert and stable pigments are normally added to give the required color.

The materials are first mixed in the required proportions and are mechanically pressed under considerable pressure into molds. They are then cured in high-pressure steam autoclaves for several hours which results in the combination of the lime with part of the siliceous aggregate to produce a hydrous calcium silicate (Tobermorite) which forms the binding medium in the finished brick. The materials listed below are used for the production of calcium silicate bricks (Anupoju, 2022).

2.1 Sand

Calcium silicate bricks contain a high amount of sand, estimated to be about 88 – 92%. It means the properties of these bricks depend upon the characteristics of the sand used. Sand has two distinct functions to perform in the manufacture of sand-lime brick, which require different properties of the material. Part of it must enter chemical combination with the lime to form the calcium-silicate bonding material. The rest of the sand grains constitute the aggregate that is bound together and forms the main body of the brick. It is necessary, therefore, that part of the sand which is expected to combine with the lime shall be in as fine a state of division as possible. If this does not occur naturally, some of the sand must be ground until it is of sufficient fineness. A good practical rule is that about 15% of the sand must pass a 100-mesh screen. The remaining 85% of the sand is intended to form the inert filler or main body of the brick. The sand used shall be well-graded and should not contain any impurities like organic matter and soluble salts. Finely divided clay may be present but it is up to 4% only which helps the brick in pressing and provides a smoother texture.

2.2 Lime

Lime content in calcium silicate bricks varies from 8 to 12%. The lime used shall be of good quality and high calcium lime. Although the proportion of lime used in making sand-lime brick is relatively small, its quality is of paramount importance. The lime must be perfectly hydrated before the bricks are pressed. Otherwise, it will expand during the steam treatment and produce internal strains which are frequently sufficient to disrupt the brick. The lime must also be sufficiently caustic to enter readily into combination with the sand.

2.3 Water

Clean water should be used for preparing calcium silicate bricks. Seawater or water containing soluble salts or organic matter of more than 0.25% is not suitable.

2.4 Pigments

Pigments are generally used to give color to the bricks. They are added to the sand and lime while mixing. The total weight of the brick contains 0.2 to 3% of the pigment quantity. The different types of pigments used to get different colors are tabulated in Table 1 (Thomasnet, 2022).

Table 1: The common pigments of sand lime bricks

S. No.	Pigment	Color
1	Carbon black	Black, grey
2	Iron oxide	Red, brown
3	Chromium oxide	Green
4	Ochre	Yellow

3 Manufacturing of Calcium Silicate Bricks

Calcium silicate (sand lime and flint lime) bricks are manufactured by mixing lime, sand, and/or crushed siliceous or flint stone, with enough water to allow the mixture to be molded under high pressure. The bricks are then steam autoclaved so that the lime reacts with the silica to form hydrated calcium silicates. Pigments can be added during the mixing stage. In their natural state, calcium silicate bricks are white to a creamy off-white color, but the addition of ochre (buff or cream colors), iron oxides (pink, red, brown, or black), or chrome oxide (green) can enable a very wide variety of colors to be produced (Sahu and Singh, 2017).

3.1 Proportioning of Materials

The relative proportions of sand and lime which are used in the manufacture of sand-lime brick are of course very important in determining the properties of the finished product. In the first step, suitable proportions of sand, lime, and pigment are taken and mixed thoroughly with 3 to 5% of water. Then paste with moldable density obtains. The mixture is molded into bricks using a rotary table press which uses mechanical pressure to press the bricks. The pressure of pressing varies from 31.5 to 63 N/mm2.It will be remembered that Michaelis's patent called for 10 to 40 parts of calcium hydroxide to 100 parts of sand. Pure calcium silicate is a gelatinous material that shrinks on drying like lime paste. To obtain a lime mortar of maximum strength, it is necessary to add enough sand to the paste so that the internal strains caused by this shrinking will be largely overcome. The hydrate is therefore 25% by volume of the sand. Assuming that sand weighs 100 pounds per cubic foot and hydrated lime weighs 40, the hydrate is about 10, Just a handful of the many great virtues are% by weight of the sand. If the hydrate carries 24% water the above proportions are equivalent to 7.6 parts of quicklime to 100 parts of sand by weight.

3.2 Mixing of Materials

Probably the most important step in the manufacture of sand-lime brick is the mixing of lime and sand. This operation is usually the determining factor in the quality of the brick. Every precaution should be taken that the mixing is thorough and efficient until the best results are obtained from the raw materials at hand. The lime and fine sand should be in intimate contact with each other so that the chemical reaction between them can readily take place. The coarse sand should be evenly distributed throughout the mass so that the proportion of voids shall be a minimum.

3.3 Compaction of Materials

The mixture of lime and sand is now ready to be pressed into the form of a brick. Pressing serves not only to give the brick its final size and shape but performs several more important functions. By bringing the sand and lime into very intimate contact with each other, the chemical combination between them can be facilitated. The compression of the material necessarily decreases the proportion of voids and therefore produces a less porous brick. The final strength of the brick has been found to depend, to some extent, on the pressure exerted in molding it. A sand-lime brick is not subject to any other change of shape or size after it leaves the press.

3.4 Hardening of Bricks

The bricks are picked by hand from the press table and piled upon iron trucks. This operation requires considerable care, for at this stage of the process the bricks are very tender and easily crushed in the hand. The trucks are designed to carry about 1100 bricks each. As soon as a truck is loaded it is pushed by hand on tracks into the hardening cylinder. The bricks are subjected to steam treatment and may be of almost any size or shape. In the final stage, bricks are placed in an autoclave. An autoclave is nothing but a steel cylinder with tightly sealed ends. The diameter of the autoclave is about 2m and the length is about 20m.This is a cylindrical shell of open-hearth steel, 70 feet long by 6 feet in diameter, built up of plates five-eighths of an inch thick, riveted together. After placing bricks in this closed chamber saturated steam pressure is released at about 0.85 to 1.6 N/mm2.The temperature inside the chamber is raised and the reaction process begins. The shell is set up horizontally and tracks for the cars are laid on the bottom of it. The front end is used as a cover and is held in position by 50 nickel-steel bolts 1inch in diameter. After erection, the cylinder is tested to a pressure of 225 pounds per square inch. Thirty-three such cylinders will hold 20 trucks, carrying 22,000 bricks. The cover of this cylinder is designed to be lifted off using a small chain block. The press is operated during the day until the cylinder is filled, and the steam treatment takes place during the night. Since it requires about 3 hours to bring the cylinder up to maximum pressure and about 1 hour to blow off the steam before the cover can be removed, the duration of curing is limited to about 10 hours. Under these circumstances, a steam pressure of about 120 pounds per square inch has been found satisfactory. Silica content in sand and calcium content in lime reacts and forms a crystal-like compound called calcium hypo silicate. This process is done for 6 to 12 hours. Finally, the obtained bricks are transported to the workplace.

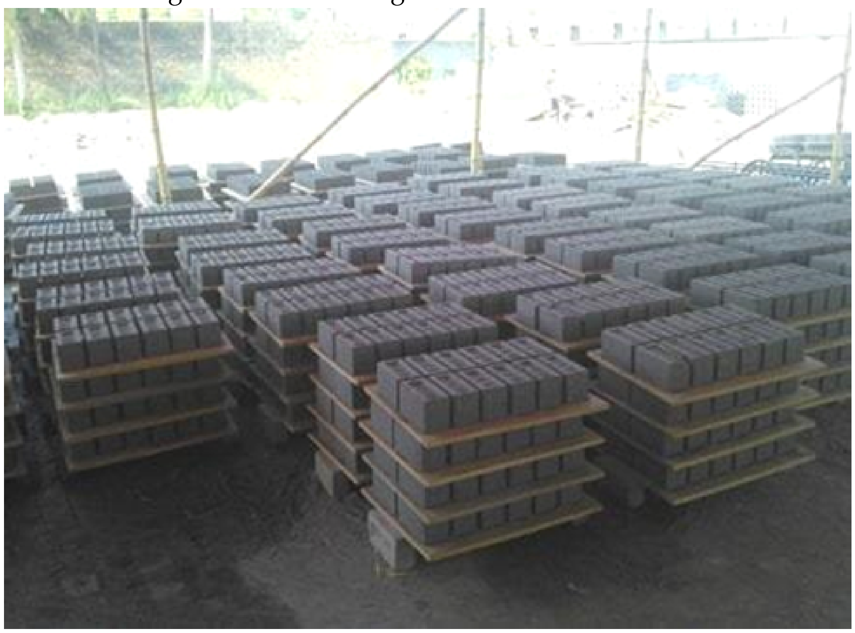
Figure 2: The 20m long steel cylinder act as an Autoclave

3.5 Stacking and Handling of Bricks

When the trucks are taken out of the hardening cylinder, they should immediately be taken to the loading platform, where the bricks are transferred to freight cars for shipment. The bricks are generally handled by one of three methods:

a) Passing them by hand from one man to another;
b) The hand carrier, which is built on the principle of a pair of tongs and is capable of picking up 8 or 10 bricks
c) The gravity carrier is a chute set on small iron legs arranged to give it a slight inclination. The bed of the chute is made up of small wooden rollers, set close together, which are free to turn as the bricks slide over them.

Figure 3: The stacking of Calcium Silicate Bricks



4 Properties of Sand Lime Bricks

The sand-lime bricks have a very smooth and uniform finish and have an attractive appearance. They are dense, strong, and tough. They are porous and therefore free from indigestion. Also, uniform in size, shape, and finish, and no plastering is required. When required, the amount of plaster is significantly less. Essential materials are quite common in the event and can be used as an alternative to clay bricks (Patil, 2019). Compared to other bricks, sand lime bricks are more uniform in color and texture, and they require less mortar to be held together. However, they cannot resist water or fire for longer periods, so they are not suitable for laying foundations or building furnaces (McDonald, 2019). The Compressive strength of sand lime bricks varies from 75 to 300 kgf/cm^2. The bending strength varies from 16 to 40 kgf/cm^2 for solid bricks of type O and U, and from 8 to 24 for hollow bricks of type U. The volume weight ranges from 1300 kg/m^3 to 1900 kg/m^3. The calcium silicate bricks are divided into porous products, up to 1500 kg/m^3, and dense products, over 1500 kg/m^3, based on their average density. The thermal conductivity of sand lime bricks varies from 0.38 to 0.87 W/(m°C). The water absorption varies from 6% to 16% of the weight of dry bricks (Titan, 2023). The sound insulation of sand lime bricks is over 64 dB. Figure 4 shows the masonry wall constructed of calcium silicate bricks.

Figure 4: A masonry wall constructed of calcium silicate bricks

5 Energy Efficiency and Environmental Sustainability

The CO_2 footprint of sand lime bricksis 300 kgs/ton and the CO_2 footprint of clay-fired bricks is 900 kgs/ton (Titan, 2023). Table 2 presents the comparative analysis of the carbon footprint of sand-lime and fired clay red bricks.

Table 2: Comparative analysis of CO2 footprint of sand lime brick and fired clay bricks

S. No.	Carbon footprint of sand-lime bricks	Carbon footprint of fired clay bricks
1	The carbon footprint of sand-lime bricks can vary depending on several factors, including the specific manufacturing process, the energy sources used, and the transportation of raw materials and finished products.	The carbon footprint of fired clay bricks can vary depending on several factors, including the specific manufacturing process, the energy sources used, and the transportation of raw materials and finished products
2	On average, the carbon footprint of producing one ton of sand-lime bricks is estimated to be around 200-300 kg of CO_2 emissions. This is significantly lower than the carbon footprint of traditional clay bricks, which can range from 800-1000 kg of CO_2 emissions per ton.	On average, the carbon footprint of producing one ton of fired clay bricks is estimated to be around 800-1000 kg of CO_2 emissions. This is due to several factors, including the energy-intensive nature of the manufacturing process, the use of fossil fuels such as coal or natural gas to fire the kilns, and the transportation of raw materials and finished products.
3	The manufacturing process requires less energy and produces fewer emissions. For example, the autoclave used in the curing process can be powered by renewable energy sources such as solar or wind power, which further reduces the carbon footprint.	To reduce the carbon footprint of fired clay bricks, manufacturers can take several steps, such as using more energy-efficient kilns, switching to renewable energy sources, and using locally-sourced raw materials to reduce transportation emissions.
4	Overall, sand-lime bricks are considered to be a more sustainable and eco-friendly alternative to traditional clay bricks, thanks to their lower carbon footprint and superior insulation properties.	Overall, while fired clay bricks are a durable and long-lasting building material, their high carbon footprint makes them less environmentally friendly compared to alternative building materials such as sand-lime bricks or earth-based construction materials.

6 Comparative Cost Analysis of Different Types of Bricks in India

Table 3 presents the comparative analysis of approximate cost of different types of bricks per piece in India. The actual cost of these bricks may vary depending on various factors such as location, supplier, quantity, and quality of the bricks (Civilgyan, 2023). Seeing the strength, durability, maintenance, life cycle and waste reduction, it can be inferred that the sand lime or calcium silicate bricks is a cheaper, alternative, economically efficient sustainable building material (Kamal, 2022).

Table 3: Comparative cost analysis of different types of bricks in India

S. No.	Type of Bricks	Approx. Cost per Piece
1	Clay Bricks	Rs. 4 to Rs. 10
2	Fly Ash Bricks	Rs. 3 or above
3	Concrete Bricks	Rs. 8 to Rs. 50
4	Hollow Bricks	Rs. 6 or above
5	AAC Blocks	Rs. 40 to Rs. 75
6	Calcium silicate bricks	Rs. 20 or above

7 Advantages of Calcium Silicate Bricks

There are many advantages of calcium silicate bricks when used in masonry construction (Patil, 2019). They are summarized below:

- The mortar required for providing plaster on calcium silicate bricks is very less.
- The color and texture of these bricks are uniforms.
- The compressive strength of sand-lime bricks is about 10N/mm2. So, they are well-suitable for multi-storied buildings.
- For constructions in clay soils, these bricks are preferable.
- The trouble of Efflorescence does not arise in the case of sand-lime bricks.
- Not only bricks, blocks, and tiles can also be made using calcium silicate.
- Sand lime bricks provide more comfort and accessibility for architects to attain desired shapes and designs.
- These bricks have accurate shapes and sizes with straight edges.
- Solar heat effect is reduced on exposed walls made of calcium silicate bricks.
- Colored sand-lime bricks do not need any finish to the wall, so, the cost reduces.
- These bricks have great fire resistance and water-repellant properties.
- Calcium silicate brick walls resist noise from outside.
- The cost of construction gets reduced by about 40% of the total cost due to the following factors.
- Wastage of calcium silicate products is very less.
- Less quantity of mortar is needed.
- The thickness of the wall can be reduced when constructed using these bricks because of their high compressive strength.

8 Disadvantages of Calcium Silicate Bricks

In some conditions, calcium silicate bricks are not suitable for masonry construction (Patil, 2019). They are summarized below:

- If the clay is available in plenty, clay bricks are more economical than calcium silicate bricks.
- These are not suitable for laying the foundation, because they cannot provide resistance to water for a longer period.
- They cannot also resist fire for longer periods so; they are not suitable for building furnaces, etc.
- The abrasion resistance of these bricks is very less so, they cannot be used as paving materials.

9 Problems Associated with Calcium Silicate Bricks

Some problems are associated with Calcium Silicate bricks (Malone, 2016). They are summarized below:

- Thermal movement is likely to be about 1.5 times that of clay brickwork. Calcium silicate brickwork, unlike clay, usually undergoes an initial irreversible shrinkage on laying (clay brickwork tends to expand) but so long as the propensity for movement is understood and catered for in the design, there is no reason why the brickwork should not perform adequately. Often this factor is not catered for in the design and this result in widespread cracking.

- Calcium silicate bricks should not be used in solid work with clay facings or backings; this is because of the propensity of the bricks to shrink in contrast with the expansion of clay brickwork. If solid walling is to be contemplated, backings of concrete bricks or blocks should be used, as these have similar movement characteristics to calcium silicate bricks. We often see an inappropriate choice of walling material for the inner leaf and these sets up opposing forces due to differential expansion, again resulting in widespread cracking.
- General construction detailing is often not attended to, particularly about providing sufficient flexibility in the wall ties to permit differential movements and allowing for discontinuity around cavity closers to prevent cracking.
- The requirement for inbuilt slip planes is often not attended to. Internally, walls of calcium silicate brickwork need to be bedded on a damp proof course to act as a slip plane and so facilitate longitudinal movements to occur – this would be equally necessary at upper floor levels, a detail that had been missed at this scheme.
- Movement control in walling is not the only issue – also consider building elements that could provide a restraining influence. For example, concrete columns or walls cast up against bricks should be avoided unless a slip membrane can be provided – as should any form of construction that will prevent free movement. In this scheme pointing to the movement joints and DPC, both provide this restraining influence.
- It is not unusual to see some form of displacement with calcium silicate bricks due to thermal expansion, for example, brickwork sliding off a damp proof course, cracking at corners, or evident disruption. By contrast, shrinkage cracking does not generally produce these manifestations.

10 Conclusions

Bricks are one of the most common building materials used in India. They have been used for thousands of years, and today, they are still a popular choice for construction projects of all sizes. Sand lime brick technology is a modern method of producing bricks that offers several advantages over traditional brick-making methods. This paper discusses the engineering viability and properties of calcium silicate bricks (Kamal, 2023). Calcium silicate bricks are often given bad press due to the issues highlighted here; however, it should be said that they are an excellent building material so long as the construction detailing required dealing with shrinkage or expansion is understood. Unfortunately more often than not this detailing is not understood and buildings are generally constructed in the same fashion as would clay bricks. They outperform clay bricks in some respects, particularly in frost resistance (Malone, 2016). The efflorescence doesn't arise in the case of sand-lime bricks. Sand lime bricks provide great comfort and accessibility for the architect to realize the specified size and design. Since the calcium silicate bricks use readily available raw materials in the manufacturing process, have excellent durability, are energy efficient, are cost-effective, and also can be recycled, therefore calcium silicate bricks can be said to be a green and sustainable building material (Kamal, 2020). This paper concludes that calcium silicate bricks are a viable alternative to conventional bricks with a lot more intangible benefits attached to them.

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