ELUCIDATION OF THE CAUSE OF EFFLORESCENCE ON CLAY-FIRED BRICKS IN BANGLADESH

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ABSTRACT

Bangladesh is a riverine country, and the availability of clay influenced the production of fired brick as one of the primary building materials. Brick is cheap, durable, and resilient to adverse climatic conditions like- floods, heavy rain, and storms. However, brick kilns are considered a significant contributor to air degradation. In spite of adverse climatic impacts, clay-fired bricks remain the number one building material. Due to the widespread source of clay in various production locations and poor quality control, efflorescence has become a significant issue of the brick masonry. Efflorescence on brick masonry is a crucial indicator of water intrusion. The understanding of the core reason for efflorescence needs to be improved amongst brick building user and the manufacturer. This research intends to identify the leading cause of efflorescence and find a sustainable solution to the problem. To achieve the objectives of this research, five brick samples were collected from 3 physiographic regions in Bangladesh. The names of the brick companies are MMB, PKB, DONE, MOON, and KBM. Each of the bricks was tested for efflorescence and ranked based on the severity of the efflorescence: 1) MMB 90%, 2) MOON and DON 50%, and 3) PKB 50%. Bricks from MMB were selected for further experiments and testing as they showed the highest level of efflorescence. The soil and brick samples underwent multiple lab experiments, such as leeching and ion extraction, and were tested for cations and mineralogical assemblages using a Scanning Electron Microscope (SEM). The results indicate that calcium was the dominant component and most likely played a significant role in the deposition of salt particles on the brick surface. The findings of this research can be used to reduce the efflorescence on Brick masonry walls by controlling the use of calcium-rich clay in the brick manufacturing process. The research opens the Scope of further engineering innovation to control inherent calcium deposition in clay while using clay in the brick manufacturing field. Thus, reducing the burden of an unhealthy built environment for the building user.

Keywords: *Efflorescence, Physiography, Soil, Brick, Clay fired brick.*

1. INTRODUCTION

The construction industry is one of the most material and energy consuming industry the world. Major building materials includes wood, stones, bricks, iron, water and plastic. Due to the hot -humid climatic conditions in Bangladesh, people are relying on indigenous climate-resilient built forms made with locally available construction materials. These buildings were made of a specific type of mud, which was soft in nature (Uddin, 2008). Bengal was under the rule of the Pala Empire Dynasty between the eighth and twelfth centuries. The Palas became known for their stone-made structures, sculptures which stood the test of time and are present today. The Bengal was in lack of availability of stone as a building material, and during this dynasty, brick, along with rich terracotta decoration, dominated the building construction. An example is the Salban in Comilla Vihar ("The Golden Past of History of Architecture in Bangladesh - Bproperty," 2020). Brick has become a premier material for constructing buildings in Bangladesh. Having no other reliable and durable building material like stone, this country has become heavily dependent on bricks (A. Haque, 2014).

The bricks' derived materials undergo various chemical and physical reactions. One such reaction is the buildup of salt crystals on the construction materials, commonly known as efflorescence (Brocken & Nijland, 2004). The efflorescence is a warning for both old and new brick masonry, indicating that water has found an entrance to the structure (A Glossary of Historic Masonry Deterioration Problems and Preservation Treatments, 1984). It can appear after construction or even a few years later (Chwast et al., 2015). These particles, although, do not hamper the integrity of the building but work as an indicator that water has entered the structure. When the absorption of water content within the brick is too high, the bonding strength of brick and mortar is reduced (B. H. A. Bakar & Brook, n.d.). This increases the owner's cost, leading to more brick production. The burning of brick is already a top contributor to environmental and ecosystem damage. About 25 to 26 percent of the wood in Bangladesh is used for brick burning every year, which causes deforestation (Jerin et al., 2016).

Clay-fired bricks are often used for the construction of buildings. Toxic fumes are emitted when the bricks are burned in the kilns; these fumes are dense in carbon monoxide and sulfur dioxides (Murugesan et al., 2023). Another issue is the formation of efflorescence, as it impacts the built environment and the quality of the bricks produced (Nazhan et al., 2023). It has been documented that the buildup of white efflorescence depends on the conditions for alkali activation and curing temperature. However, efflorescence might not be the only cause of brick degradation, and it can leave a negative impression on building users due to the appearance on the built structure (Temuujin et al., 2016). The basic knowledge regarding efflorescence is that it is the crystalline solution generated on brick walls. However, few research papers could identify the basic chemistry regarding the formation of efflorescence and how we can eliminate it after its formation has already occurred. Widely available solutions to eradicate the efflorescence of brick construction are applicable at the building users' end. As a result, the brick manufacturers are reluctant and feel no obligation to enhance the quality of their products. This research aims to improve the understanding of effloresce and find a solution to this problem. The proposed solution is targeted at the brick manufacturing stage to produce bricks less prone to efflorescence. Thus, the research findings will reduce the socioeconomic burden on the building owner and encourage the brick manufacturers to produce efflorescence resisting better quality bricks.

Objectives of the study

The Primary objective of this paper is to elucidate the cause of efflorescence on clay fired bricks in Bangladesh. More specifically, finding the association between the elemental makeup of soils used for brick production and efflorescence on clay-fired bricks in Bangladesh.

2. METHODOLOGY

2.1 Study area and sample collection

With the increase in demand for cost-efficient building materials, the manufacturing of clay-fired bricks has become a widespread industrial venture for the people of Bangladesh. Brick kilns surround the outskirts of the majority of the big cities located in the country (Hassan et al., 2019). The first brick and soil samples used for this study were collected from brick kilns in Rajshahi and Cumilla. Three of the four collected samples were collected from companies in Rajshahi. The names of these companies are Done, Moon, and PKB, and the lone company from Cumilla is MMB. In search of a possible solution for the efflorescence problem, another brick field was visited within the Dhaka division, located in Narayanganj. Salt samples were scraped from the bricks and stored in plastic containers. They were used for detailed cation analysis and went under a SEM (Scanning Electron Microscope

2.2 Efflorescence test

The efflorescence test aimed to determine the resistive capabilities of the bricks against efflorescence buildup. For this test, the selected bricks were placed vertically on a tray filled with distilled water. The height of the water poured on the tray did not exceed 2.5 centimeters, and the samples were kept in a well-ventilated room where the temperature was between 20 and 30 degrees. This method must be followed for all the bricks used. They were observed for around three weeks to check the efflorescence and buildup on the bricks. When the 3-week period was over, the tray was rid of the water entirely, and only the bricks remained. They were left under observation for four days during this time, and the levels of efflorescence built up. The levels of efflorescence were divided into three stages:

Moderate (50%): The bricks show little to no presence of efflorescence on their surface.

Heavy (more than 50%): There are noticeable changes to the brick's original state where the levels of efflorescence are noticeable.

Serious (90% and above): Most of the brick is covered with efflorescence. You see the color white more than red.

2.3 Lab Experiments

2.3.1 Batch Experiment

The new sieve samples were also heated in an oven at 105 degrees Celsius. Furthermore, four beakers were selected, and each was filled with a solution made by mixing distilled water and Hydrochloric Acid (HCL), where the pH dropped to 2. To duplicate the results, each sample was tested twice. Each beaker was filled with 1 liter of the liquid solution mixed with 100 grams of soil. A magnet was placed in all four beakers and set on top of a custom-made magnetic stirrer. The samples were collected at different time intervals. Before they were picked up, they were stirred. These samples were tested for their electrical conductivity, salinity, and pH to check particles' leaching. By definition, leaching is the removal of soluble substances from the upper layer of soil by percolating precipitation (Leaching | Geochemistry of Soil | Britannica, n.d.).

They went under an absorption test to check the absorptive capacity of the brick. Four of the collected raw brick samples were used for this experiment. Each of the bricks was placed in four different bowls, of which two were red and two were blue. To duplicate the results, the blue bowls were filled with 6 liters of distilled water, and the other two red bowls were filled with 6 liters of pH two acidic water made from mixing hydrochloric acid and distilled water. The bricks were placed individually and were set for observation for 30 days. At certain intervals, water from the bowls was extracted and placed in a 45 ml vial to check the electrical conductivity, salinity, and pH. After the period above, the bricks were carefully removed and weighted individually. The following formula was used to identify how much water they could absorb.

Water Evaporated = Total water at the beginning – Water left after the experiment

During the first absorption test, two bricks were submerged in distilled water, where the pH was brought down to 2 with the help of hydrochloric acid. In that test, it could be seen that the electrical conductivity of the samples was decreasing over time. To further confirm those results, it was decided that a repetition was in order, but the samples would be sealed in air-tight containers this time. The goal was to check whether or not confinement would make any difference to the results.

To set up the experiment, two red bricks were broken down and sealed inside 200 ml bottles made of plastic. They were put aside for 48 hours and were only opened during the time of reading. They, too, were tested for EC, pH, and salinity.

2.4 Laboratory Analysis:

2.4.1 Cation Analysis

The main goal of the cation test was to determine the key components responsible for efflorescence on the bricks. The test determines the presence of cations such as Sodium, Potassium, lithium, Aluminum, Ammonium, and Magnesium ions.

2.4.2 Determination of salt, soil, and brick mineralogy using SEM

The scanning electron microscope model SU3800 captured high-resolution images of the salt and soil samples. The main goal of this test was to identify the elements present and to compare the results with the cation test results. The results indicate that the presence of Potassium is evident in all the test results.

3. RESULTS AND DISCUSSION

3.1 Batch Experiment

The following data represents the results that were received during an absorption test. For this test, two raw bricks were acquired. Both of the samples were dipped in 6 litres of distilled water. The samples were observed for 30 days. They were tested for EC (Electrical Conductivity), pH, and salinity at specific intervals. The bricks (labelled Brick 1 and Brick 2, respectively), dipped in distilled water, showed only a slight increase in all the parameters over the observation period. The first reading was taken 30 minutes after the dipping process. To check the parameters, 45 millilitres of water were taken from the bowl where the bricks were placed. The water was stored in a falcon tube and measured using pH, salinity and EC meters.

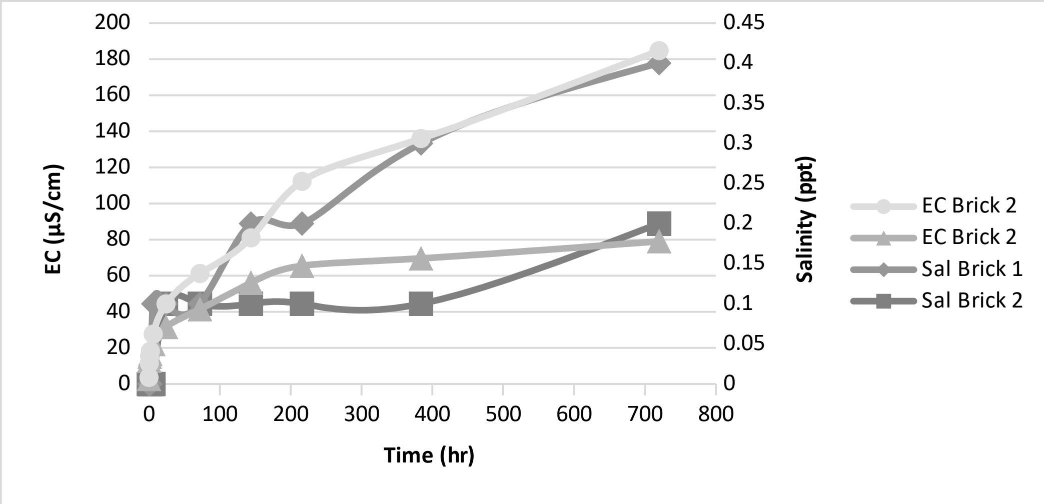

Figure 1 Electrical Conductivity and Salinity of water used for batch experiment with Brick 1 and Brick 2

The results for the Electrical Conductivity (primary Y-axis) of the water used for ion extraction from brick 1 and brick 2 indicate a gradual increase since the beginning of the experiment. In the first 30 minutes, the EC for Brick 1 and Brick 2 jumped significantly from 3.62 mS and 2.82 mS to 11.47 mS and 12.83 mS, respectively. At the 24-hour mark, the results almost doubled in value. The trajectory of Brick 1 surpassed that of Brick 2. This trend continued throughout the process as the EC of Brick 1 skyrocketed to 184.7 by the end of the experiment at day 720 hours. Unlike its counterpart, brick 2 saw a steady rise, reaching 79.1 by the end of the experiment. During the batch experiment, there was only a slight increase in the salinity of the water used for ion extraction from brick 1 and brick 2 and salinity (secondary Y-axis). The salinity of the water during the batch experiment ranges between 0-0.4 ppt for brick 1 and 0-0.2 ppt for brick 2. The results of the salinity shows that there was no significant change in the first 72 hours. After 72 hours salinity of the water continued to increase gradually till the end of the experiment (720 hours). The salinity data confirms that there is no relation between sodium and efflorescence due to the low observed values of salinity, this is further confirmed by the SEM scanning which show that there is no sodium present in the samples.

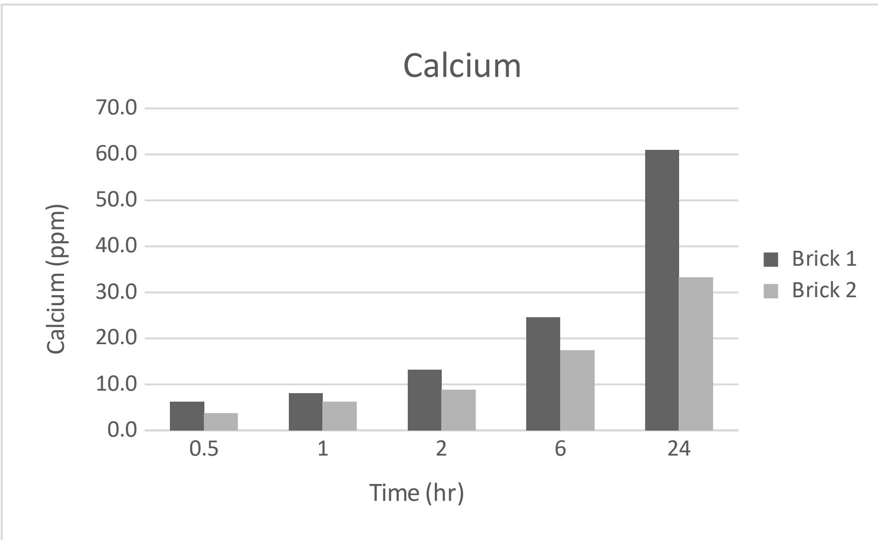

Figure 2 Chart depicting the increase in calcium

The chart generated shows that the amount of calcium ion increased with time. The time frame was within 24 hours, and during those hours, the calcium jumped from below 10 ppm to above 15 ppm after 6 hours. Brick 1 showed the most significant change as it jumped to 70 ppm at the 24-hour mark, whereas brick two slightly increased from around 15 to above 30 ppm.

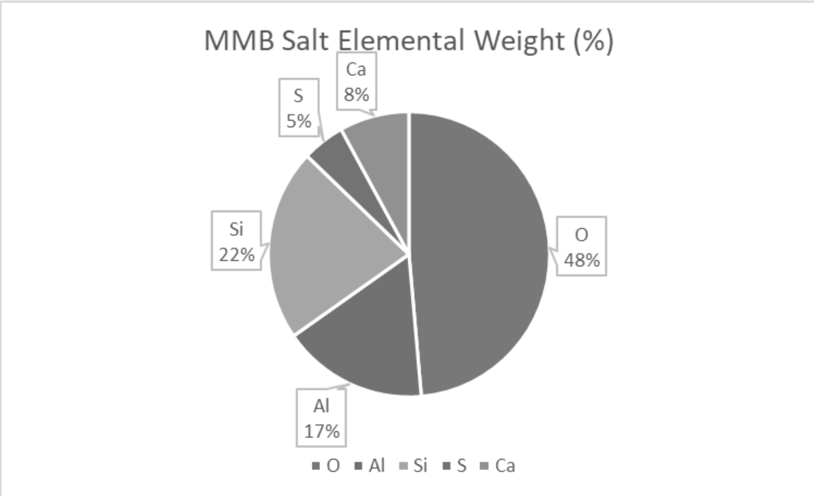

Figure 3 Weight of Calcium found using SEM

After putting the salt of MMB bricks samples under a scanning electron microscope, it was evident that the presence of calcium (8%) is significant. Even though there are other elements, such as silicon and aluminium, none plays a significant role in the formation of efflorescence. The results of SEM are consistent with the presence of calcium ions extracted from brick samples Figure 2, thus confirming that calcium indeed is a one of the leading causes of efflorescence.

3.2 Ion Extraction

To search for a solution, each liquid sample collected during the leaching test went under an ion extraction test. Out of all the elements present in the cation spectrum, calcium saw a meteoric rise. It was assumed with this result that calcium has a strong connection with the rise in efflorescence. To further confirm this theory, similar studies were consulted. In an experiment to link co-extrusion technology with the process of producing the food item known as sausage, the introduction of high concentration made way to the rapid formation of white efflorescence on the food, the amount of efflorescence present was 90%. It was produced with the addition of 20-30% CaCl2 after being kept in storage for eight weeks. Another batch produced with much less CaCl2 saw slow efflorescence formation (Hilbig et al., 2020). Just as it was hypothesized at the beginning of this project, the presence of calcium significantly impacts efflorescence production.

3.3 Effects of the brick industry on agriculture

Soil plays a crucial role as it is a critical component in producing clay bricks. It is still primarily used for making bricks despite alternative methods used abroad to reduce soil input. Farmers in Bangladesh forcefully sell their fertile soil for short-term profit, which induces a domino effect where other farmers follow in the footsteps of their neighbours (Biswas et al., 2018). These soils are rich in nutrients such as calcium, magnesium, and phosphorous. If the soil is compromised, it will cause problems such as the build up of efflorescence during construction. Calcium and sulfur-rich soils help crystalize salt during brick construction. The weathering of salts can be a significant cause of the degradation of porous building materials (Pel et al., 2004). When salts enter the porous areas of both bricks and mortars, it severely affects their durability by weakening the tensile strength, and this phenomenon has been called the salt attack (B. H. Bakar et al., 2011).

3.4 Proposed appropriate technology for mitigation

In order to prevent efflorescence from occurring, we believed that to stop the intrusion of water into the bricks, we must coat them with a product that will make it difficult for water to penetrate. To find such a solution, extensive research was needed. Various international journals emphasized the use of siloxane-based resin (Ershad-Langroudi & Sadat-Shojai, 2009). It is a mixture made mainly from silicon and oxides and is sprayed on bricks to prevent water from entering them. The siloxane material was used to waterproof the roof of a historic building. In this study, the results showed that even fourteen months after the application of the product, there was no efflorescence formation on the building (Maravelaki-Kalaitzaki, 2007). Even though it is a good solution, it will significantly increase the owners' costs because they must import the product from abroad. Importing 1 gallon of liquid siloxane can cost around 3500 taka.

To find a better solution, we have to look at something produced locally. During this search, we came across the KGM brick field, which is located in Narayanganj. The owners over there integrated a unique technique into their brick-making process. They mix white urea, a crystalline solid containing 46% nitrogen, with their soil (Azeem et al., 2014). Another study noted that Pastulla can improve the effect of corrosion in cement-based materials by hydrolyzing urea (Qian et al., 2022). The process is to keep the mixed soil stored for one year. Throughout the year, the urea will help decay the soil. The decaying process allows the soil to develop a protective layer that prevents iron from various water sources from entering. Two brick samples were collected and put through an efflorescence test to test this theory further. After observing the samples for three weeks, there was little to no efflorescence present on the samples. At the moment, the price of urea for dealers in Bangladesh is 25 taka per kilogram. So, urea seems the optimum solution as it is cheaper than the siloxane solution and it can be applied during the manufacturing process.

3.5 Limitations and sustainable solutions available

Although using white urea seems like a reliable solution, the main challenge is running this experiment on a larger scale. For this to occur, we need the collaboration of not one but multiple brick companies who are willing to strain their budget and implement the technique of using white urea. Not only this, further research is required in order to find a sustainable solution. There are innovative means of preventing efflorescence worldwide. The main target should be to introduce and produce those techniques locally. Since water is a crucial factor in activating the salts in the concrete, a study was conducted in Khulna. In this study, an old wall covered in efflorescence was selected to be experimented on. It had zero contact with any source of water. So, minimal water was added to a high-quality cement mixture and was used on that wall. After the wall had seen most of its efflorescence disappear, it was not completely fixed (Argha & Bari, 2018). The primary solution to the efflorescence problem, which can be suggested, is to start using soils in the northern regions of Bangladesh. They have approximately the least amount of calcium in there. If combined with urea, the probability of wiping out efflorescence might also increase, even though the suggestion of bringing new soil types to the equation may seem like a temporary solution because clay-fired bricks are not environmentally friendly. Newer studies should be conducted to find a permanent remedy

4. CONCLUSION

The concept and study of efflorescence is a growing concern in the construction industry of Bangladesh. Literature review prevails that significant work has been done in the relevant field; however, most of them suggest damage repairing policy that needs to be conducted after the brickwork is done and efflorescence takes over. This research was conducted to identify the root cause of efflorescence and identified that calcium is the common reagent that causes efflorescence when it comes into contact with water/ humidity. The provided solution is based on this research findings and is focused on improving the manufacturing process of brick and eradicating the cause of efflorescence during brick production. This research confirmed an abundance of calcium in the collected samples through the ion and a scanning electron microscope. This research also helped with the understanding of calcium distribution in the soils of Bangladesh. With the use of white urea as a solution, this research has found a way to prevent primary efflorescence. Further studies can be conducted to find more sustainable solutions that will help to prevent efflorescence and eliminate it.

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