Critical Review on Bricks

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ABSTRACT

Brick is one of the most important materials for construction industries. The current trend in brick manufacturing has emphasis on use of post consumer based and industrial by-product. Most of the with various recycled waste as foundry, sand, granite, sawing waste, harbor sediments, ash, clay, waste and fine waste of boron, sewage, sludge waste glass. The objective of this paper is to explain about manufacturing of bricks in past and present status and also about harmful effect of these practices. In this paper author explain about various techniques to enhance quality of bricks and also to reduce the hazardous effect on environment.

Keywords--- Bricks, Manufacturing process of bricks

I. INTRODUCTION

Brick is one of the most important materials for construction industries. The consumption of earth-based materials as clay, shale and sand in brick production resulted in resource depletion, environmental degradation, and energy consumption and emission of green house gases. Virgin resources are mined from riverbeds and hillsides to service brick industry leaving mines areas un-reclaimed. Environmental degradation accompanies mining activities with air pollution and remains after the mines cease operations, leaves scars on the landscape. The brick was anciently produced by mixing the virgin resources, forming the bricks, drying them and then firing them [1]-[3]. The current trend in bricks manufacturing has emphasis on use of post-consumer wastes and industrial by-products in the production process. Most of the researchers went through enhancing the clay brick quality and properties by mixing the clay with various recycled wastes as foundry sand, granite sawing waste, harbour sediments, sugarcane ash, clay waste and fine waste of boron, sewage sludge, waste glass from structural wall and other different wastes [4]-[26]. More researches were held in developing bricks from wholly waste materials without exploiting any sort of natural resources, in order to achieve sustainability. They used entirely wastes in bricks making like waste treatment residual, granite waste, paper sludge, straw fibers, waste treatment sludge, fly ash and with few other wastes[27]-[28]. The conventional method of bricks making has caused serious environmental contamination represented by the enormous emissions of green house gases (GHG) resulted in unusual climate changes as smog, acid rain and global warming. Furthermore, energy as fuel and electricity showed a drastic consumption during the traditional manufacturing of bricks led to highly economical expenditures. As a result, vast forests are in current deforestation in order to utilize their woods and trees as source of energy in the firing stage of bricks production. Hence, recycling the wastes in the bricks production appears to be viable solution not only to environmental pollution but also economical option to design of green building. However, the chronic problem of (GHG) and energy consumption has not yet been tackled properly as most of the previous works were mainly focused on recycling the wastes traditionally in the bricks. Several researches addressed the amount of (GHG) emission and their impacts on the context as well as the energy consumption [28]-[29]. Few researches took the initiative in developing eco-friendly bricks in an economical environmental concern [30]-[33].

II. MANUFACTURING OF BRICKS

2.1 Manufacturing of Bricks the Earliest Decades

The brick was historically manufactured by an ancient method dating back to 6000 B.C called the soft mud process in which a relatively moist clay is pressed into simple rectangular moulds by hands. To keep the sticky clay from adhering to the moulds, the moulds may be dipped in water immediately before being filled, producing brick with a relatively smooth, dense, surface know as water struck brick [1]. The bricks manufacturing was slightly developed from the sift mud process to the dry press process was used for the clay that shrinks while drying. Clay mixed was placed in steel moulds and pressed by a machine. The
Ancient civilians recognized the fired brick as more durable and weathering resistance. Therefore, the fired brick was more favorable than the sun dried brick [2]. The ancient fired brick was manufactured by forming the mixed clay in moulds and then bricks were fired by stacking them in a loose array called clamp covering the clamp with earth or clay, building a wood fire under the clamp and maintaining the fire for several days [3].

2.2 Manufacturing of Bricks in the Present

This section of paper will exhibit the classification of bricks, raw materials and way of manufacturing with respect to the current trend within the current twenty years.

2.2.1 Concrete Bricks

Concrete blocks are made by blending Portland cement, sand and other aggregates with a small amount of water, then blowing the mixture into moulds. The blocks are removed from the moulds, held for an initial setting period, and then cured in a kiln or autoclave. The entire curing process usually is accomplished within 24 hours [3].

2.2.2 Model structure Calcium Silicate Bricks

It can be called as sand lime and sometimes flint lime. They are made from carefully selected clean and high grade sand or crushed flint is mixed intimately with (5-8)% of high calcium hydrated lime \([\text{Ca(OH)}_2]\) with controlled quantity of water. The plastic mixture is then molded into bricks and autoclaved under pressure at steam atmosphere at (3-8) hours depending on the pressure-temperature level. Under these conditions lime react with silica to form a complex of hydro di-calcium silicate, similar to those form when the water react with Portland cement which acts as cementing material and provide high dimension stability [3].

2.2.3 Clay Bricks

The majority of bricks used are made from clay and shale; they are used preliminary in the construction of walls by jointing bricks into established bonding arrangement. Clay is an abundant raw material with various uses and properties. It is a complex group of material that consist of minerals commodities, each having different mineralogy, geological occurrence, technology and applications. They are natural earthy fine grained minerals of secondary origin and composed of an aluminates silicate structure with an additional iron, alkalis and alkaline earth element. Common clays are sufficiently plastic to permit ready molding and when firing, they vitrify below 1100°C [27]. The clay brick has been traditionally manufactured by mixing the ground clay with water then forming into desired shape and size, drying and firing. Clay brick can be classified based on the compressive strength and water absorption values according to BS 3921, 1985 as illustrated in table 1.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Class Average</th>
<th>Compressive strength(N/mm²)</th>
<th>Average absorption(%boiling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>A</td>
<td>70</td>
<td>4.5</td>
</tr>
<tr>
<td>Engineering</td>
<td>B</td>
<td>50</td>
<td>7.0</td>
</tr>
<tr>
<td>Load bearing brick</td>
<td></td>
<td>50-100</td>
<td>No specific</td>
</tr>
<tr>
<td>Damp-proof course1</td>
<td></td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>Damp-proof course</td>
<td></td>
<td>2.5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

The excessive extraction of clay and the removal of top soil have resulted in an enormous depletion of clay. Therefore, there have been remarkable efforts from researches for producing new type of clay bricks developed from various waste materials. Hence, recycling of wastes in clay brick will save the clay from the evitable depletion and reduce the environmental contamination of waste, whereby contributing to sustainability. Aeslina et al. [4]. Produced bricks by recycling cigarette butts (CBs) into fired clay bricks. Physico-mechanical properties such as density, strength, and thermal conductivity and leachate characteristics of fired clay bricks manufactured with different percentages of CBs were investigated and discussed. Hanifi et al. [5] presented an earthquake-resistant material with high compressive strength. He elaborated the compressive strength of fiber reinforced mud bricks made out of clay, cement, basaltic pumice, lime and gypsum using plastic fiber, straw, polystyrene fabric as fibrous ingredients, each at a time. The behavior of the fibers in mud bricks and the effects of the different geometrical shapes of the interface layers were investigated in detail. Rahman [6] produced bricks from clay-sand mixed with different percentages of rice husk ash and burnt in a furnace for different firing times. The firing durations at 1000°C were (2, 4, and 6) hours. The effects of rice husk ash contents on workable mixing water content, atterberg limits, linear shrinkage, density, compressive strength and water absorption of the bricks were investigated. Demir et al. [7] investigated the utilization potential of kraft pulp production residues in clay bricks. Due to the organic nature of pulp residue, pore-forming ability in clay body was investigated. For this purpose, increasing amount of residue (0, 2.5, 5, and 10) percent by weight was mixed with raw clay brick. All samples were fired at 900°C. Effect on shaping, plasticity, density and mechanical properties were investigated. (2.5–5) percent residue additions were found to be effective for the pore forming in clay body with acceptable mechanical properties. Demir [8] investigated the utilization potential of processed waste tea (PWT) in clay bricks. The effects of (PWT) material addition on the durability and mechanical properties of the bricks were investigated. Due to the organic nature of PWT, pore-
forming in fired body and binding ability in unfired body in clay body was investigated. In order to get comparable results, different ratios of the waste (0, 2.5, and 5) percent by mass were added to the raw-clay brick. Test specimens were produced by the extrusion method. Caroline et al. [9] investigated the liability of recycled slag of welding flux (SWF) as substitute of sand in the production of multiple-use mortars and clay for the production of ceramic bricks. Ceramic pieces have been made containing kaolin tie sedimentary clay up to 10 percent by weight of SWF. The pieces were prepared by uniaxial pressing and fired at 950°C. The various properties determined after firing were: linear shrinkage, water absorption, apparent porosity, apparent density, and flexural strength. For ceramic bricks, SWF can also be used as partial substitute for red clay. Both the applications of SWF significantly contributes for the reduction of the ambient impact; on one hand, reducing the extraction of natural sand and clay, on the other hand, contributing for the reduction of the risk of ground water contamination due to the inadequate disposal of the SWF. Alonso et al. [10] developed a comparative study to produce ceramic bricks from clay with two types of foundry sand (green and core sand) (0-50) percent by weight. The specimens were physically and mineralogically evaluated the scaling up analyzed and an optimization study was developed. Clay/green sand bricks with (35 percent green core and 25 percent green sand) fired at 1050°C have the better physical properties values, while the mineralogy is not significantly affected. Romualdo et al. [11] investigated the possibilities of using the granite sawing wastes as alternative ceramic raw materials in the production of ceramic bricks and tiles. Granite sawing waste was mixed (20, 25, 30, 35, 40, 45, 50, 55, and 60) percent by weight of red clay. Characterization of samples was carried out with the determination of density, particle size distribution, surface area and chemical composition. Results for the tests in ceramic compositions showed that the samples with (10-30) percent granite wastes have physical and mineralogical characteristics similar to those of conventional ceramic raw materials. Kay et al. [12] conducted a pilot experiment at a full-scale in recycling the harbour sediments 40 percent by weight mixed with waste bricks and clay. The leaching of the bricks were not hazardous to soil or groundwater neither by their use, in masonry, nor afterwards, when they will be deposited as mineral demolition mass. Iker et al. [13] had done an investigation in producing high heat conductivity resistance bricks from perlite and clay with some binding materials such as cement, gypsum, lime, bitumen and clay were used for manufacturing perlite brick. Mechanical properties as unit weight, compressive strength, volume reduction and heat conductivity values were examined according to combination properties, and specialties of perlite bricks at various weights. Faria et al. [14] recycled the sugarcane bagasse ash waste through replacement of natural clay by up to 20 percent by weight. The waste sample was characterized by its chemical composition, X-ray diffraction, differential thermal analysis, particle size, morphology and pollution potential. Technological properties as linear shrinkage, water absorption, apparent density, and tensile strength were evaluated. Results for scanning electro-microscope (SEM) showed that the sugarcane bagasse ash waste is mainly composed by crystalline silica particles and it could be used as filler in clay bricks, thus enhancing the possibility of its reuse in a safe and sustainable way. Taner [15] studied the feasibility of utilizing clay and fine waste (CW and FW) of boron as a fluxing agent in production of red mud (RM) brick. The mineralogical and mechanical tests showed that the usability of boron wastes as a fluxing agent in the production of RM bricks was possible. J.A. Cusido’et al. [16] had successfully developed lighter, more thermal and acoustic insulating clay brick, compared with conventional clay-bricks by mixing sewage 15 percent by weight sludge, with 5 percent by weight forest debris mixed with clay. The study was conducted using an Environmental protection Agency recommended sampling train and portable sampling tubes that were thermally desorbed and analyzed by gas chromatography/mass spectrometry. Eliche et al. [17] recycled the waste produced in biodiesel production plants, as spent earth from biodiesel filtration and the by-product of glycerine, in producing lightweight structural bricks. Spent earth from biodiesel filtration were mixed (5, 10, 15, 20) percent by weight, (5, 10, 15) percent by weight of glycerine were all mixed with clay. Results for chemical composition and physical properties are indicated that the use of waste decreased bulk density and increased apparent porosity of sintered samples. Values on mechanical properties decreased, due to the increase in water absorption and water suction, but were higher than those required by the standards Carretero [18] produced clay brick from very different clay, calcareous and non-calcareous. The mechanical resistance, pore size distribution and critical pore diameter did not clearly reflect the influence of shaping techniques. Vorrada et al. [19] recycled wasted glasses from structural glass walls up to 45 percent weight into clay mixtures. Physical and mechanical properties of clay bricks were investigated. The compressive strength as high as (26–41) MPa and water absorption as low as (2–3) percent were achieved for bricks containing (15–30) percent by weight of glass content and fired at 1100°C. When the glass waste content was 45 percent by weight, apparent porosity and water absorption was rapidly increased. Martinez et al. [20] replaced clay in a ceramic body with different proportions of sludge. Clay brick was incorporated waste sludge in (1, 2.5, 5, 7.5, 10, and 15) percent by weight. Bulk density, linear shrinkage, water suction, water absorption and compressive strength were evaluated. Michele [21] studied the potential utilization of tontite as coloring agent in clay bricks by admixing up to 9 percent to four industrial clay bodies. Mechanical properties of the bricks were assessed. No relevant changes of process and product parameters were found up to 3 percent tontite. Additions over 5 percent induce significant
variations, such as increase of working moisture and water absorption, decrease of bulk density and bending strength. Therefore, the optimum proportion of tontion was found to be 3 percent. Ismail [22] investigated the potential utilization of organic residues in clay bricks as sawdust, tobacco residues and grass were mixed with clay at (0, 2.5, 5, and 10) percent by weight. Effects on shaping, plasticity, density, and mechanical properties were investigated. It was observed that the fibrous nature of the residues did not create extrusion problems. However, higher residue addition required a higher water content to ensure the right plasticity. The organic residue can be utilized in an environmentally safe way as organic pore-forming agents in brick-clay. Dondi et al. [23] investigated the utilization of funnel and panel glass of TV and PC glass waste up to 5 percent mixed with clay. Results for leaching test demonstrated no significant environment. Kae Leong [24] investigated the addition of municipal solid waste incineration fly ash slag (MSWI) on fired clay bricks. Results for leaches test met the current thresholds. Results for the mechanical properties met the Chinese National Standard (CNS) for building requirements for second-class brick. Eliche et al. [25] recycled various industrial wastes such as urban sewage sludge, bagasse, and sludge from the brewing industry, olive mil wastewater, and coffee ground residue were blended with clay to produce bricks. The influence of the waste on the mechanical and thermal properties was investigated. The incorporation of coffee grounds and olive mill wastewater of clay was more beneficial, with compressive strength values similar to bricks without waste and with a 19% improvement in thermal conductivity.

2.3 Manufacturing Bricks in the Future

The brick industry continues to seek more sustainable means of manufacturing as using alternative fuel sources and incorporating recycled content in order to alleviate the hazardous impacts of the GHG emission and save the non-renewable source of energy from the none escapable depletion. The brick industry has recently encountered a substantial evolution represented by launching new approaches in manufacturing non fired bricks. From the economical and environmental point of view, the unfired bricks diverse sharply from the conventional fired brick. Developing bricks by more sustainable, sophisticated, constitutional and eco-friendly approach will contribute to environmental protection. Oti et al. [30] produced unfired clay brick by recycling a ground granulated blast furnace Slag (GGBS) activated with an alkaline lime and Portland cement. The brick was produced by making flowable mix with high w/c ranging in (1.5- 5.5). Results for compressive strength ranged in (5-10) MPa at 28 days, the water absorption varied from (7-14) percent, and sonic pulse velocity fell in range between (2.556-2.819) km/s. Unlike the conventional method for producing bricks, the new procedure neither used clay and shale nor required high temperature kiln firing, having significant environmental and ecological benefits. Alternative fuels should be further studied since most of the brick plants depend on fossil fuel as the main source of energy for the industrial operation. Although, few plants went through utilizing of pet coke which is a by-product of oil refining, others utilized methane gas which is natural gas as a source of energy as an initiative to reduce the energy resources depletions, but these gases still consume lots of energy and emit lots of GHG emission [34]. Therefore, serious steps should be taken in this Endeavour and the promotion for the usage of renewable energy as solar energy, wind energy or water energy will be the optimum solution for this issue.

III. TYPES OF BRICKS

There are thousands of types of bricks that are named for their use, size, forming methods, origin, quality, texture, and materials.

3.1 Categorized by Manufacture Method:

- Extruded made by being forced through an opening in a steel die, with a very consistent size and shape.
- Wire-cut cut to size after extrusion with a tensioned wire which may leave drag marks
- Molded shaped in moulds rather than being extruded
- Machine-molded clay is forced into moulds using pressure
- Handmade clay is forced into moulds by a person
- Dry-pressed similar to soft mud method, but starts with a much thicker clay mix and is compressed with great force.
3.2 Categorized by Use

**Common or building** a brick not intended to be visible, used for internal structure

**Face** brick used on exterior surfaces to present a clean appearance

**Hollow** not solid, the holes are less than 25% of the brick volume.

**Perforated** holes greater are than 25% of the brick volume.

**Keyed** indentations in at least one face and end to be used with rendering and plastering

**Paving** brick intended to be in ground contact as a walkway or roadway.

**Thin brick** with normal height and length but thin width to be used as a veneer

3.3 Specialized use bricks

**Chemically resistant** bricks made with resistance to chemicals.

1. **Acid brick** acid resistant bricks.
2. **Engineering** type of hard, dense, brick used where strength, low water porosity or acid (flue gas) resistance are needed. Further classified as type A and type B based on their compressive strength.

**Accrington** type of Engineering brick (England).
1. **Fire** or refractory highly heat-resistant bricks.
2. **Clinker** vitrified brick.
3. **Ceramic glazed** fire bricks with a decorative glazing.

[38]

IV. METHOD OF MANUFACTURE

Three basic types of bricks are unfired, fired and chemically set brick. Each type is manufactured differently

**Mud brick (unfired bricks)**

Unfired bricks, also known as mud bricks, are made from a wet, clay-containing soil mixed with binder’s material. They are air-dried until ready for use.

**Fired brick**

Fired bricks are burned in a kiln which makes them durable. Modern, fired, clay bricks are formed in one of three processes are soft mud, dry press, or extruded. Depending on the country, either the extruded or soft mud method is the most common, since they are the most economical.

Normally, brick contains the following ingredients

- **Silica (sand)** – 50% to 60% by weight
- **Alumina (clay)** – 20% to 30% by weight
- **Lime** – 2 to 5% by weight
- **Iron oxide** – ≤ 7% by weight
- **Magnesia** – less than 1% by weight

**Molded bricks**

It starts with the raw clay, preferably in a mix with 25–30% sand to reduce shrinkage. The clay is first ground and mixed with water to the desired consistency. The clay is then pressed into steel moulds with a hydraulic press. The shaped clay is then burned in kiln at 900–1000 °C to achieve strength.

**Extruded bricks**

For extruded bricks the clay is mixed with 10–15% water (stiff extrusion) or 20–25% water (soft extrusion) in a pug mill. This mixture is forced through a die to create a long cable of material of the desired width and depth. This mass is then cut into bricks of the desired length by a wall of wires. Most structural bricks are made by this method as it produces hard, dense bricks, and suitable dies can produce perforations as well. The introduction of such holes reduces the volume of clay needed, and hence the cost. Hollow bricks are lighter and easier to handle, and have different thermal properties from solid bricks. The cut bricks are hardened by drying for 20 to 40 hours at 50 to 150 °C before being fired. The heat for drying is often waste heat from the kiln. European-style extruded bricks or blocks are used in single-wall construction with finishes applied on the inside and outside. Their many voids comprise a greater proportion of the volume than the solid, thin walls of fired clay. Such bricks are made in 15-, 25-, 30-, 42-, and 50-cm widths. Some models have very high thermal insulation properties, making them suitable for zero-energy buildings.

**Dry-pressed bricks**

The dry-press method is similar to the soft mud method, but starts with a much thicker clay mix, so it forms more accurate, sharper-edged bricks. The greater force in pressing and the longer burn make this method more expensive [39].

**Rail kilns**

In modern brickworks, this is usually done in a continuously fired tunnel kiln, in which the bricks are fired as they move slowly through the kiln on conveyors, rails, or kiln cars, which achieves a more consistent brick product. The bricks often have lime, ash, and organic matter added, which accelerates the burning process.

**Bull's Trench Kilns**

In India, brick making is typically a manual process. The most common type of brick kiln in use there is the Bull's Trench Kiln (BTK), based on a design developed by British engineer W. Bull in the late 19th century.

An oval or circular trench is dug, 6–9 meters wide, 2-2.5 meters deep, and 100–150 meters in circumference. A tall exhaust chimney is constructed in the centre. Half or more of the trench is filled with "green" (unfired) bricks which are stacked in an open lattice pattern to allow airflow. The lattice is capped with a roofing layer of finished brick.

In operation, new green bricks, along with roofing bricks, are stacked at one end of the brick pile; cooled finished bricks are removed from the other end for transport to their destinations. In the middle, the brick workers create a firing zone by dropping fuel (coal, wood, oil, debris, and so on) through access holes in the roof above the trench.

The advantage of the BTK design is a much greater energy efficiency compared with clamp or Scove kilns. Sheet metal or boards are used to route the airflow through the brick lattice so that fresh air flows first through the recently burned bricks, heating the air, then
through the active burning zone. The air continues through the green brick zone (pre-heating and drying the bricks), and finally out the chimney, where the rising gases create suction that pulls air through the system. The reuse of heated air yields savings in fuel cost.

As with the rail process above, the BTK process is continuous. A half-dozen labourers working around the clock can fire approximately 15,000–25,000 bricks a day. Unlike the rail process, in the BTK process the bricks do not move. Instead, the locations at which the bricks are loaded, fired, and unloaded gradually rotate through the trench [40].

V. MANUFACTURING OF BRICKS

Although the basic principles of manufacture are fairly uniform, individual manufacturing plants tailor their production to fit their particular raw materials and operation. Essentially, brick are produced by mixing ground clay with water, forming the clay into the desired shape, and drying and firing. In ancient times, all molding was performed by hand. However, since the invention of brick-making machines during the latter part of the 19th century, the majority of brick produced in the United States have been machine made.

5.1 Phases of Manufacturing

The manufacturing process has six general phases:
1) Mining and storage of raw materials.
2) Preparing raw materials.
3) Forming the brick.
4) Drying.
5) Firing and cooling.
6) De-hacking and storing finished products (Figure 5.1).

![Diagrammatic Representation of Manufacturing Process](image)

**Mining and Storage**

Surface clays, shales and some fire clays are mined in open pits with power equipment. Then the clay or shale mixtures are transported to plant storage areas. Continuous brick production regardless of weather conditions is ensured by storing sufficient quantities of raw materials required for many days of plant operation. Normally, several storage areas (one for each source) are used to facilitate blending of the clays. Blending produces more uniform raw materials, helps control color and allows raw material control for manufacturing a certain brick body.

**Preparation**

To break up large clay lumps and stones, the material is processed through size-reduction machines before mixing the raw material. Usually the material is processed through inclined vibrating screens to control particle size.

**Forming**

Tempering, the first step in the forming process, produces a homogeneous, plastic clay mass. Usually, this is achieved by adding water to the clay in a pug mill, a mixing chamber with one or more revolving shafts with blade extensions. After pugging, the plastic clay mass is ready for forming. There are three principal processes for forming brick: stiff-mud, soft-mud and dry-press.

**Stiff-Mud Process**

In the stiff-mud or extrusion process, water in the range of 10 to 15 percent is mixed into the clay to produce plasticity. After pugging, the tempered clay goes through a de-airing chamber that maintains a vacuum of 15 to 29 in. (375 to 725 mm) of mercury. De-airing removes air holes and bubbles, giving the clay increased workability and plasticity, resulting in greater strength. Next, the clay is extruded through a die to produce a column of clay. As the clay column leaves the die, textures or surface coatings may be applied. An automatic cutter then slices through the clay column to create the individual brick. Cutter spacing’s and die sizes must be carefully calculated to compensate for normal shrinkage that occurs during drying and firing. About 90 percent of brick in the United States are produced by the extrusion process.

**Soft-Mud Process**
The soft-mud or molded process is particularly suitable for clays containing too much water to be extruded by the stiff-mud process. Clays are mixed to contain 20 to 30 percent water and then formed into brick in moulds. To prevent clay from sticking, the moulds are lubricated with either sand or water to produce “sand-struck” or “water-struck” brick. Brick may be produced in this manner by machine or by hand.

**Dry-Press Process**

This process is particularly suited to clays of very low plasticity. Clay is mixed with a minimal amount of water (up to 10 percent), then pressed into steel moulds under pressures from 500 to 1500 psi (3.4 to 10.3 MPa) by hydraulic or compressed air rams.

**Drying**

Wet brick from molding or cutting machines contain 7 to 30 percent moisture, depending upon the forming method. Before the firing process begins, most of this water is evaporated in dryer chambers at temperatures ranging from about 100 °F to 400 °F (38 °C to 204 °C). The extent of drying time, which varies with different clays, usually is between 24 to 48 hours. Although heat may be generated specifically for dryer chambers, it usually is supplied from the exhaust heat of kilns to maximize thermal efficiency. In all cases, heat and humidity must be carefully regulated to avoid cracking in the brick.

**Hacking**

Hacking is the process of loading a kiln car or kiln with brick. The number of brick on the kiln car is determined by kiln size. The brick are typically placed by robots or mechanical means. The setting pattern has some influence on appearance. Brick placed face-to-face will have a more uniform color than brick that are cross-lined. The packages and cubes are configured to provide openings for handling by forklifts.[41]

**Firing**

Brick are fired between 10 and 40 hours, depending upon kiln type and other variables. There are several types of kilns used by manufacturers. The most common type is a tunnel kiln, followed by periodic kilns. Fuel may be natural gas, coal, sawdust, and methane gas from landfills or a combination of these fuels. In a tunnel kiln brick are loaded onto kiln cars, which pass through various temperature zones as they travel through the tunnel. The heat conditions in each zone are carefully controlled, and the kiln is continuously operated. A periodic kiln is one that is loaded, fired, allowed to cool and unloaded, after which the same steps are repeated. Dried brick are set in periodic kilns according to a prescribed pattern that permits circulation of hot kiln gases. Firing may be divided into five general stages: 1) final drying (evaporating free water); 2) dehydration; 3) oxidation; 4) vitrification; and 5) flashing or reduction firing. Although the actual temperatures will differ with clay or shale, final drying takes place at temperatures up to about 400 °F (204 °C), dehydration from about 300 °F to 1800 °F (149 °C to 982 °C), oxidation from 1000 °F to 1800 °F (538 °C to 982 °C) and vitrification from 1600 °F to 2400 °F (871 °C to 1316 °C). Clay, unlike metal, softens slowly and melts or vitrifies gradually when subjected to rising temperatures. Vitrification allows clay to become a hard, solid mass with relatively low absorption. Melting takes place in three stages: 1) incipient fusion, when the clay particles become sufficiently soft to stick together in a mass when cooled; 2) vitrification, when extensive fluxing occurs and the mass becomes tight, solid and nonabsorbent; and 3) viscous fusion, when the clay mass breaks down and becomes molten, leading to a deformed shape. The key to the firing process is to control the temperature in the kiln so that incipient fusion and partial vitrification occur but viscous fusion is avoided. The rate of temperature change must be carefully controlled and is dependent on the raw materials, as well as the size and coring of the brick being produced. Kilns are normally equipped with temperature sensors to control firing temperatures in the various stages. Near the end, the brick may be “flashed” to produce color variations.

**Cooling**

After the temperature has peaked and is maintained for a prescribed time, the cooling process begins. Cooling time rarely exceeds 10 hours for tunnel kilns and from 5 to 24 hours in periodic kilns. Cooling is an important stage in brick manufacturing because the rate of cooling has a direct effect on color.

**De-hacking**

De-hacking is the process of unloading a kiln or kiln car after the brick have cooled, a job often performed by robots. Brick are sorted, graded and packaged. Then they are placed in a storage yard or loaded onto rail cars or truck for delivery. The majority of brick today are packaged in self-contained, strapped cubes, which can be broken down into individual strapped packages for ease of handling on the jobsite. The packages and cubes are configured to provide openings for handling by forklifts.

VI. **PROPERTY OF BRICKS**

All properties of brick are affected by raw material composition and the manufacturing process. Most manufacturers blend different clays to achieve the desired properties of the raw materials and of the fired brick.

This improves the overall quality of the finished product. The quality control during the manufacturing process permits the manufacturer to limit variations due to processing and to produce a more uniform product. The most important properties of brick are as follows:

**Durability**

The durability of brick depends upon achieving incipient fusion and partial vitrification during firing. Because compressive strength and absorption values are also related to the firing temperatures, these properties, together with saturation coefficient, are currently taken as predictors of durability in brick specifications.

**Color**

The color of fired clay depends upon its chemical composition, the firing temperatures and the method of firing control. Of all the oxides commonly
found in clays, iron probably has the greatest effect on color. Regardless of its natural color, clay containing iron in practically any form will exhibit a shade of red when exposed to an oxidizing fire because of the formation of ferrous oxide. When fired in a reducing atmosphere, the same clay will assume a dark (or black) hue. Creating a reducing atmosphere in the kiln is known as flashing or reduction firing.

Darker colors are associated with higher firing temperatures, lower absorption values and higher compressive strength values. However, for products made from different raw materials, there is no direct relationship between strength and color or absorption and color.

**Texture, Coatings and Glazes**

Many brick have smooth or sand-finished textures produced by the dies or moulds used in forming. A smooth texture, commonly referred to as a die skin, results from pressure exerted by the steel die as the clay passes through it in the extrusion process. Most extruded brick have the die skin removed and the surface further treated to produce other textures using devices that cut, scratch, roll, brush or otherwise roughen the surface as the clay column leaves the die. Brick may be tumbled before or after firing to achieve an antique appearance. Many manufacturing plants apply engobes ( slurries) of finely ground clay or colorants to the column. Engobes are clay slips that are fired onto the ceramic body and develop hardness, but are not impervious to moisture or water vapor. Sands, with or without coloring agents, can be rolled into an engobe or applied directly to the brick faces to create interesting and distinctive patterns in the finished product. Although not produced by all manufacturers, glazed brick are made through a carefully controlled ceramic glazing procedure. There are two basic variations of glazing: single-fired and double-fired. Single-fired glazes are sprayed on brick before or after drying and then kiln-fired at the normal firing temperatures of the brick. Double-fired glazes are used to obtain colors that cannot be produced at higher temperatures. Such a glaze is applied after the brick body has been fired and cooled, then refired at temperatures less than 1800 °F (982 °C). Glazes are available in a wide variety of colors and reflectance’s. Unlike engobes, glazes are impervious to water and water vapor

**Size Variation**

Because clays shrink during both drying and firing, allowances are made in the forming process to achieve the desired size of the finished brick. Both drying shrinkage and firing shrinkage vary for different clays, usually falling within the following ranges:

- **(a) Drying shrinkage:** 2 to 4 percent
- **(b) Firing shrinkage:** 2.5 to 4 percent

Firing shrinkage increases with higher temperatures, which produce darker shades. When a wide range of colors is desired, some variation between the sizes of the dark and light units is inevitable. To obtain products of uniform size, manufacturers control factors contributing to shrinkage. Because of normal variations in raw materials and temperature variations within kilns, absolute uniformity is impossible. Consequently, specifications for brick allow size variations.

**Compressive Strength and Absorption**

Both compressive strength and absorption are affected by properties of the clay, method of manufacture and degree of firing. For a given clay and method of manufacture, higher compressive strength values and lower absorption values are associated with higher firing temperatures. Although absorption and compressive strength can be controlled by manufacturing and firing methods, these properties depend largely upon the properties of the raw materials [42].


[37] Types of brick Wikipedia

[38] Method of manufacture Wikipedia

[39] Pakistan Environmental Protection Agency, Brick Kiln Units (PDF file)
