

Manufacturing of Brick

Abstract: This *Technical Note* presents fundamental procedures for the manufacture of clay brick. The types of clay used, the three principal processes for forming brick and the various phases of manufacturing, from mining through storage, are discussed. Information is provided regarding brick durability, color, texture (including coatings and glazes), size variation, compressive strength and absorption.

Key Words: absorption, clays, color, cooling, compressive strength, de-hacking, drying, durability, firing, forming, hacking, manufacturing, mining, preparation, shales, size variation, texture.

SUMMARY:

- Brick is made of clay or shale formed, dried and fired into a durable ceramic product.
- There are three ways to form the shape and size of a brick: extruded (stiff mud), molded (soft mud) and dry-pressed. The majority of brick are made by the extrusion method.
- Brick achieves its color through the minerals in the fired clay or through coatings that are applied before or after the firing process. This provides a durable color that never fades or diminishes.
- Brick shrink during the manufacturing process as vitrification occurs. Brick will vary in size due to the manufacturing process. These variations are addressed by ASTM standards.
- The method used to form a brick has a major impact on its texture. Sand-finished surfaces are typical with molded brick. A variety of textures can be achieved with extruded brick.
- Brick manufacturers address sustainability by locating manufacturing facilities near clay sources to reduce transportation, by recycling of process waste, by reclaiming land where mining has occurred, and by taking measures to reduce plant emissions. Most brick are used within 500 miles of a brick manufacturing facility.

INTRODUCTION

The fundamentals of brick manufacturing have not changed over time. However, technological advancements have made contemporary brick plants substantially more efficient and have improved the overall quality of the products. A more complete knowledge of raw materials and their properties, better control of firing, improved kiln designs and more advanced mechanization have all contributed to advancing the brick industry.

Other *Technical Notes* in this series address the classification and selection of brick considering the use, exposure and required durability of the finished brickwork.

RAW MATERIALS

Clay is one of the most abundant natural mineral materials on earth. For brick manufacturing, clay must possess some specific properties and characteristics. Such clays must have plasticity, which permits them to be shaped or molded when mixed with water; they must have sufficient wet and air-dried strength to maintain their shape after forming. Also, when subjected to appropriate temperatures, the clay particles must fuse together.

Types of Clay

Clays occur in three principal forms, all of which have similar chemical compositions but different physical characteristics.

Surface Clays. Surface clays may be the upthrusts of older deposits or of more recent sedimentary formations. As the name implies, they are found near the surface of the earth.

Shales. Shales are clays that have been subjected to high pressures until they have nearly hardened into slate.

Fire Clays. Fire clays are usually mined at deeper levels than other clays and have refractory qualities.

Surface and fire clays have a different physical structure from shales but are similar in chemical composition. All

three types of clay are composed of silica and alumina with varying amounts of metallic oxides. Metallic oxides act as fluxes promoting fusion of the particles at lower temperatures. Metallic oxides (particularly those of iron, magnesium and calcium) influence the color of the fired brick.

The manufacturer minimizes variations in chemical composition and physical properties by mixing clays from different sources and different locations in the pit. Chemical composition varies within the pit, and the differences are compensated for by varying manufacturing processes. As a result, brick from the same manufacturer will have slightly different properties in subsequent production runs. Further, brick from different manufacturers that have the same appearance may differ in other properties.

MANUFACTURING

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.

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 and 6) de-hacking and storing finished products (see [Figure 1](#)).

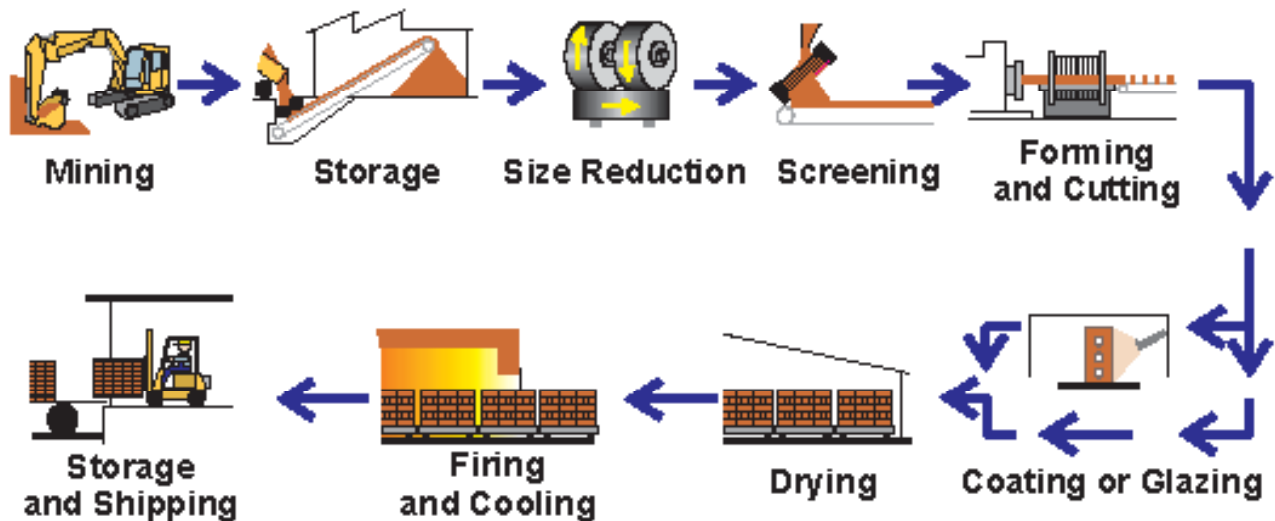


Figure 1

Diagrammatic Representation of Manufacturing Process

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 (see [Photo 1](#)).

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.



Photo 1

Clay or Shale Being Crushed and Transported to Storage Area



Photo 2

Clay is Thoroughly Mixed with Water in Pug Mill Before Extrusion

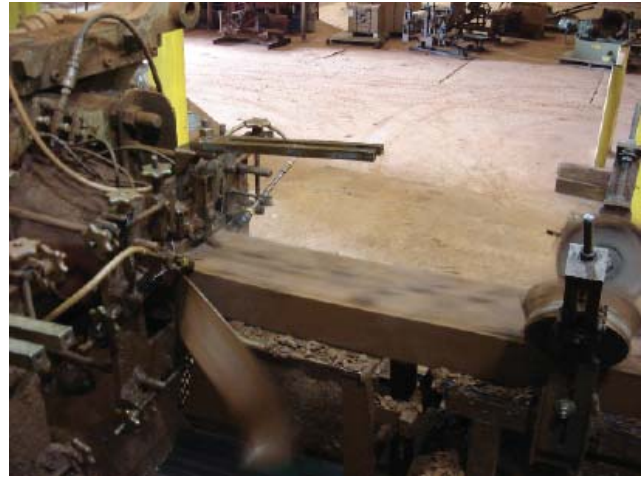


Photo 3

After Mining, Clay is Extruded Through a Die and Trimmed to Specified Dimension Before Firing

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 (see [Photo 2](#)), 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 (see [Photo 3](#)), 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 (see [PROPERTIES, Textures, Coatings and Glazes](#)). An automatic cutter then slices through the clay column to create the individual brick. Cutter spacings and die sizes must be carefully calculated to compensate for normal shrinkage that occurs during drying and firing (see [PROPERTIES, Size Variation](#)). 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 molds. To prevent clay from sticking, the molds 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 molds 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-set or placed face-to-back.

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, methane gas from landfills or a combination of these fuels.

In a tunnel kiln (see [Photo 4](#)), 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. All except flashing are associated with rising temperatures in the kiln. 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 (see [PROPERTIES, Color](#)).

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 (see [Photo 5](#)). Brick are sorted, graded and packaged. Then they are placed in a storage yard or loaded onto rail cars or trucks 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.



Photo 4

Brick Enter Tunnel Kiln for Firing

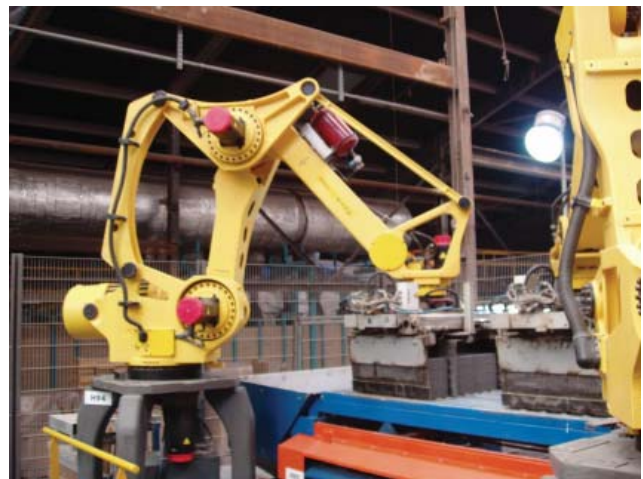


Photo 5

Robotic Arm Unloading Brick After Firing

PROPERTIES

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 1) durability, 2) color, 3) texture, 4) size variation, 5) compressive strength and 6) absorption.

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. However, because of differences in raw materials and manufacturing methods, a single set of values of compressive strength and absorption will not reliably indicate the degree of firing.

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.

Given the same raw material and manufacturing method, 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 molds 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 (see [Photo 6](#)). 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 reflectances. Unlike engobes, glazes are impervious to water and water vapor.

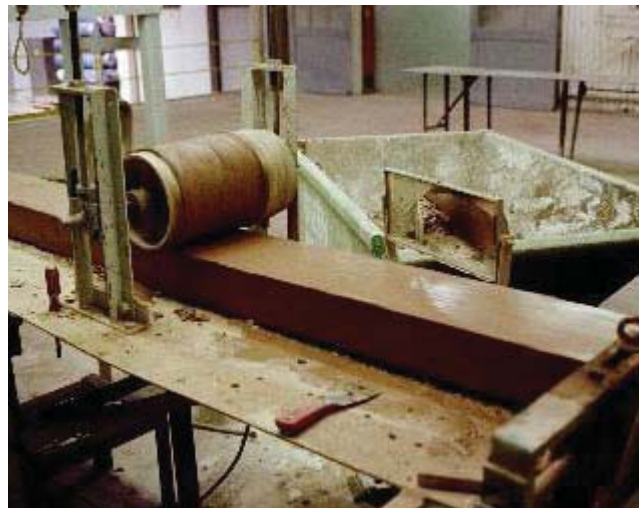


Photo 6

Some Brick Textures are Applied by Passing Under a Roller After Extrusion

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:

- Drying shrinkage: 2 to 4 percent
- 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.

ENVIRONMENTAL ISSUES

Brick manufacturing is one of the most efficient uses of materials to produce a product. Brick plants are typically located close to raw material sources. Processed clay and shale removed in the forming process before firing are returned to the production stream. Brick not meeting standards after firing are culled from the process and ground to be used as grog in manufacturing brick or crushed to be used as landscaping material. There is virtually no waste of raw materials in manufacturing brick.

Brick manufacturing uses readily available raw materials, including some waste products. The primary ingredient, clay, has been termed an “abundant resource” by many authorities including the American Institute of Architects [Ref. 1], confirming that depletion of clay is not a concern. Nonhazardous waste products from other industries are sometimes used. Examples include using bottom- and fly-ash from coal-fired generators, using other ceramic materials as grog, using lubricants derived from processing organic materials in the forming of brick, and using sawdust as a burnout material.

The brick industry’s goal is to reduce resources used in the manufacturing process. Although water is used in brick manufacturing, it is not chemically altered but is evaporated into the atmosphere. By using storage tanks to recirculate and reuse water, potable water demand can be cut dramatically. Brick manufacturers are continuously looking for ways to minimize use of water. **Photo 7** shows one plant using a storage tank to hold recirculated water for reuse in brick production.



Photo 7

Left Storage Tank Captures Used Water from Manufacturing Process; Water is Cleaned, Cooled and Moved to Holding Tank for Reuse

While natural gas is the most frequently used energy source for brick manufacturing, many manufacturers are using waste products, such as methane gas from landfills and sawdust, for brick firing.

The brick industry recognizes the need for compliance with state and federal regulations for clean air and the environment. Air emissions are minimized with controls such as scrubbers installed on kiln exhausts. Dust in plants

is controlled through the use of filtering systems, vacuums, additives and water mists. Mined areas are reclaimed by replacing overburden and topsoil so the resulting property can be used for a wide variety of functions, including farmland, residential and commercial sites, and even wetlands.

Current manufacturing processes for brick are similar in scope to those used for the past 3500 years. Over this period of time, it has been demonstrated that brick are safe and durable products for society. The long service life of brickwork is a key component of sustainable structures and pavements.

The Brick Industry Association has adopted the following environmental policy statement:

The brick industry recognizes that the stewardship of our planet lies in the hands of our generation. Our goal is to continually seek out innovative, environmentally friendly opportunities in the manufacturing process and for the end use of clay brick products. As demonstrated over time, we are committed to manufacturing products that provide exceptional energy efficiency, durability, recyclability, and low maintenance with minimal impact on the environment from which they originate. We will ensure that our facilities meet or exceed state and federal environmental regulations, and we will continue to partner with building professionals to help them in using our products to create environmentally responsible living and working spaces for today's and future generations.

SUMMARY

This *Technical Note* on manufacturing brick is the first in a series covering the manufacturing, classification and selection of brick. It provides a synopsis of the manufacturing process and discusses the various properties that are a function of this process. More detailed descriptions of the ceramic properties of brick are not within the purview of the Brick Industry Association. This type of information is more readily available through the National Brick Research Center, ceramic engineers and educators.

The information and suggestions contained in this Technical Note are based on the available data and the combined experience of engineering staff and members of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this Technical Note are not within the purview of the Brick Industry Association and must rest with the project architect, engineer and owner.

REFERENCES

1. American Institute of Architects, *Environmental Resource Guide*, The American Institute of Architects, Canada, 1998.
2. Campbell, J. W. P. and Pryce, W., *Brick, A World History*, Thames and Hudson, New York, NY, 2003.