

2 APPLIED PROCESSES AND TECHNIQUES

CERAMIC TILE MANUFACTURING PROCESS

The ceramic tile manufacturing process consists of a series of successive stages, which can be summarised as follows:

- Raw materials preparation
- Pressing and drying of the green body
- Firing, with or without glazing
- Additional treatments
- Sorting and packing

Depending on whether the product to be made is glazed or not, and whether single fire, twice fire or third fire is involved, the tile will or will not be glazed in a given process, or the order of the glazing and firing stages will be suitably rearranged. (Figure 1).

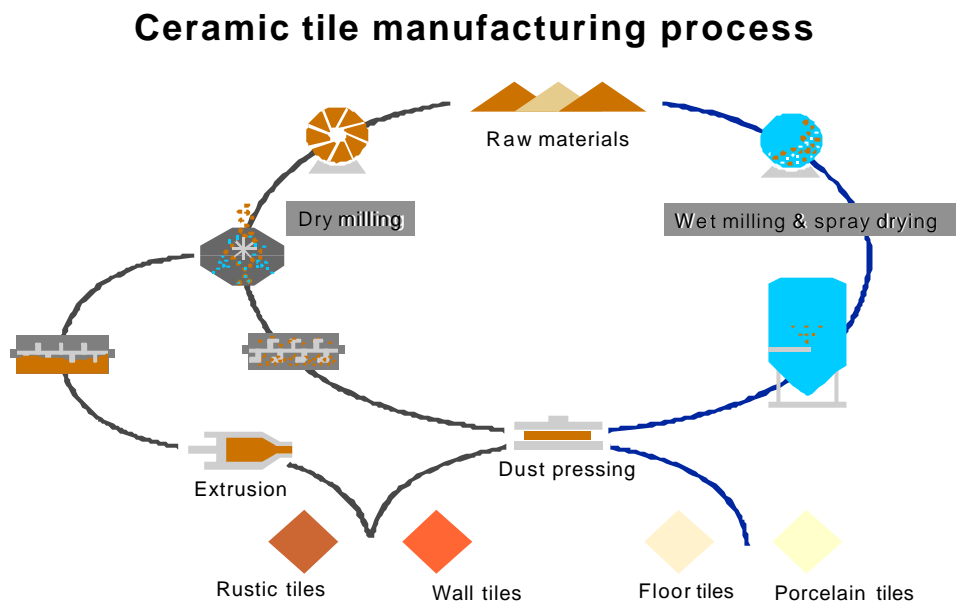


Figure 1. Diagram of the manufacturing processes considered.

Raw materials preparation – Wet milling – Spray drying - Pressing - Drying - (Firing) - Glazing - Firing (Variable without glazing and with or without polishing) (Variable with cogeneration).

Raw materials preparation – Dry milling - Pressing - (Firing) - Glazing - Firing.

Raw materials preparation - Mixing - Extrusion - (Glazing) - Firing.

Raw materials preparation

The ceramic process starts by selecting the raw materials required for the body composition, which are mainly clays, feldspars, sands, carbonates and kaolins.

In the traditional ceramic industry, the raw materials are generally used as-mined or after some minor treatment. As natural raw materials are involved, preliminary homogenisation is required in most cases to ensure consistent characteristics.

Dry or wet milling

After a first mixing of the body components, the mixture is usually dry milled (hammer or pendulum mills) or wet milled (continuous or batch ball mills).

The resulting milled material exhibits different characteristics depending on whether dry or wet milling is used. In dry milling, fragmentation occurs and particle aggregates and agglomerates remain, with a larger particle size (there are particles larger than 300 microns) than by the wet method (all particles are smaller than 200 microns). A decisive factor in selecting the type of milling to be used is the capital outlay required in each case.

Wet milling and spray drying

Wet milling and subsequent spray drying are currently the most widely implemented methods in ceramic floor and wall tile manufacture by the single-fire process, owing to the important technical improvements they provide. (Figure 2).

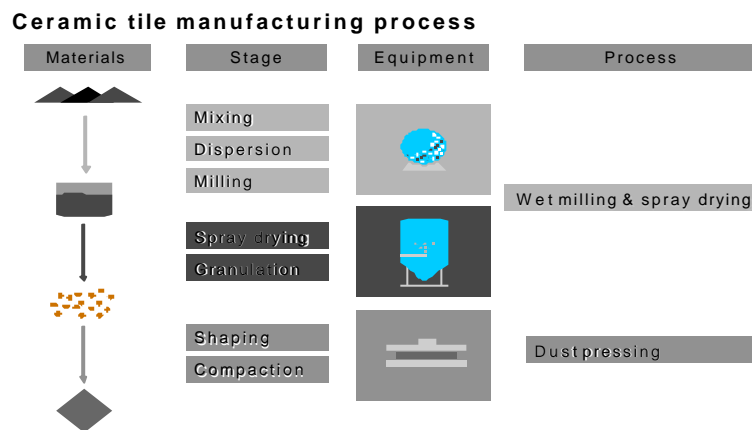


Figure 2.

In wet milling, the raw materials can be wholly or partially fed into the ball mills, which is normally the case, or they can be directly dispersed.

Part of the water contained in the resulting suspension (slip) is removed by spray drying to obtain a product with the required moisture for each process stage. Spray drying is the most widely implemented drying method in tile manufacture.

In this drying process, the fine drops of sprayed suspension come into contact with hot air to yield a solid with a low water content.

The moisture content of the body slip usually ranges from 0.0-0.45 kg water/kg dry solid. The spray-drying process reduces the water content to 0.05-0.07 kg water/kg dry solid.

Spray drying takes place according to the scheme shown in Figure 3:

- Pumping and spraying the slip.
- Hot gas generation and feed.
- Drying by contact of hot gas-slip drops.
- Separation of spray dried powder from the gases.

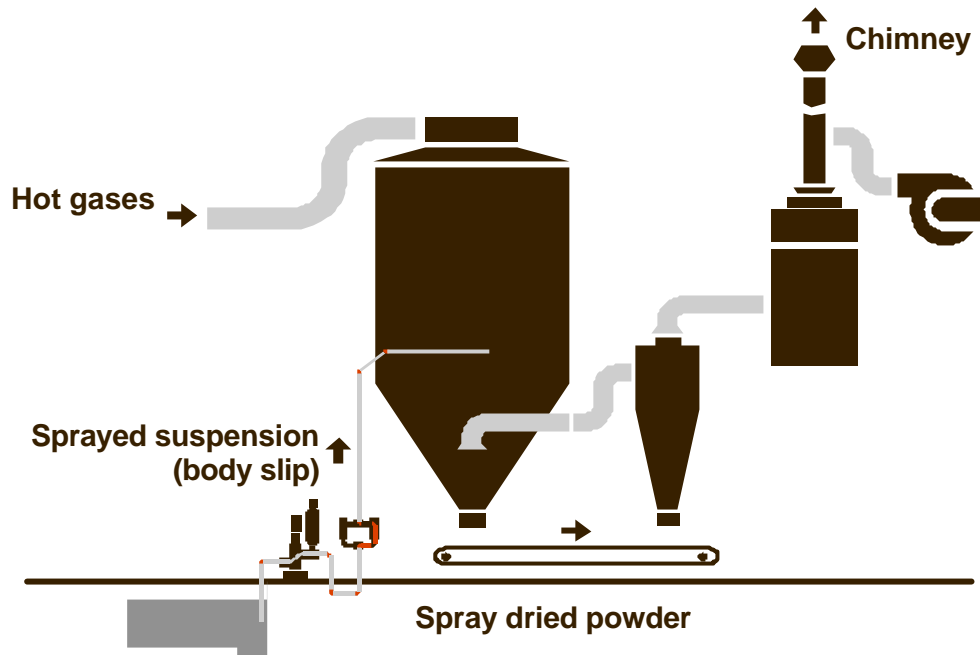


Figure 3. Schematic illustration of the spray-drying process.

The spray-drying operation is as follows. The slip from the milling facility storage tanks, with a 60-70 % solids content and appropriate viscosity (around 1000cp.), is fed into the spray dryer by reciprocating pumps.

The slip is sprayed as a fine mist, which dries on coming into contact with the hot gas stream. The gases come from a conventional air-natural gas burner or are exhaust gases from a cogeneration turbine.

The granulate, with a moisture content of between 5,5 and 7%, is discharged onto a conveyor belt and conveyed to the silos for subsequent pressing.

The stream of gases used to dry the slip and produce the powder are exhausted through the top of the spray dryer. The gases have a high water content and very fine suspended dust particles.

The use of the spray-drying process to obtain the raw material for the body (spray-dried powder) provides important advantages that favour the development of subsequent manufacturing process stages. One of the most important advantages is producing highly uniform, more or less spherical hollow granules that provide the spray-dried powder with high flowability and facilitate press die filling and the pressing of large-size tiles.

Another advantage worth mentioning is that it allows performing two operations, namely drying and granulation, simultaneously with same facilities. On the other hand, control of process variables is very simple, although the considerable rigidity of the operating boundary conditions imposed by the facility's geometry and constructive characteristic, need to be taken into account. Further to be noted is the continuous character of the process, which allows process automation.

The energy costs of the drying process are quite high, but energy efficiency can be raised by heat recovery from the gases and electricity generation by installing cogeneration turbines.

Mixing

In this body preparation stage, the water and raw materials making up the body composition are closely mixed to a consistent paste that is readily mouldable by extrusion.

Tile forming

Dry pressing

Dry pressing (at 5-7% moisture content) with hydraulic presses is the most common tile forming method. Forming takes place by mechanically compressing the paste in the die and is one of the most cost-efficient forming methods for making ceramic ware with a regular geometry.

In pressing, the oil-hydraulic press system drives the rams into the powder bed in the die. The main hydraulic press characteristics are as follows: high compaction force, high productivity, easy adjustment and consistency in holding the set pressing cycle schedule.

The pressing facilities have developed significantly in the last few years with very sophisticated, easily adjustable and highly versatile programmers.

Extrusion

Tile forming by extrusion processes basically consists of putting the plastic body through a die that produces a constant tile cross section.

The equipment involved is made up of three main parts: a driving system, the die and the cutter. The most common driving system is an auger.

Drying of the green ceramic bodies

After forming, the tile body is dried to reduce the moisture content (0.2-0.5 %) to appropriately low levels for the firing and eventual glazing stages.

In the dryers that are commonly used in the ceramic industry, heat is transferred mainly by convection from hot gases to the tile surface, and also slightly by radiation from these gases and from the dryer walls to the tile surface.

Therefore, during the drying of ceramic bodies, a simultaneous and consecutive displacement of the water takes place through the wet solid and the gas. The air used must be sufficiently dry and hot, because it not only serves to remove the water from the solid but also to provide energy in the form of heat to evaporate the water.

At present, the bodies are dried in vertical or horizontal dryers. After shaping, the bodies are placed in the dryer where they face a hot gas countercurrent. The hot gases come from an air-natural gas burner or from the kiln cooling stack. The main heat transfer mechanism between the air and the bodies is convection.

In the vertical dryers, the pieces are fed into baskets consisting of several decks of rollers. The groups of baskets move upward through the dryer, where they come into contact with the hot gases. The temperature in this type of dryer is normally less than 200°C and the drying cycles range from 35-50 minutes.

The horizontal dryers are designed like the rollers kilns. The items are fed onto different decks inside the dryer, and conveyed horizontally on the rollers. Burners located on the sides of the kiln produce the hot drying air countercurrent. The maximum temperature in these types of facilities is usually higher than in the vertical dryers (around 350°C) and the drying cycles are shorter, between 15 and 25 minutes.

Overall, horizontal dryers have a lower energy consumption compared to the vertical dryers due to a better arrangement of the items inside the dryer and a lower thermal mass.

The resulting emission from the drying stage is a gaseous stream with a temperature of about 110°C, with a very low concentration of suspended particulates from the tile surfaces being drawn along in the exhaust stream.

Firing, with or without glazing

Unglazed products are fired after the drying stage. Similarly, in the case of glazed twice-fire products, the green bodies are fired after drying.

Glazing

Glazing involves applying one or more coats of glaze with a total thickness of 75-500 microns onto the tile proper surface by different methods. Glazing is done to provide the fired product with a series of technical and esthetical properties such as impermeability, cleanability, gloss, colour, surface texture, and chemical and mechanical resistance.

The nature of the resulting glaze coating is essentially vitreous, although in many cases the glaze structure contains crystalline elements.

Glazes and frits

The glaze, just like the ceramic body, is made up of a series of inorganic raw materials. The major glaze component is silica (glass former), as well as other elements that act as fluxes (alkalis, alkaline earths, boron, zinc, etc.), opacifiers (zirconium, titanium, etc.), and as colouring agents (iron, chromium, cobalt, manganese, etc.).

A wide variety of glazes are formulated depending on the type of product, firing temperature, and the desired effects and properties of the finished product.

In other ceramic processes (porcelain artware, sanitary ware), glazes are formulated that only contain crystalline, natural or synthetic raw materials, which contribute the necessary oxides. However, in ceramic floor and wall tile manufacture, raw materials of a glassy nature (frits) are used. These are prepared from the same crystalline materials that have previously undergone heat treatment at high temperature.

Frits: Nature, advantages, composition and manufacture.

Frits are vitreous compounds, insoluble in water, made by melting at high temperature (1500°C) followed by fast cooling of the raw materials mixture. Most of the glaze compositions used in tile manufacture have a larger or smaller fritted part, which can consist of a single frit or blend of different types of frits.

For a given chemical composition using frits has certain advantages compared to using unfritted raw materials, such as:

Insolubility of certain chemical elements.

Lower toxicity; owing to its size and structure, the frit tends to form less ambient dust than the original raw materials, thus reducing the hazard associated with raw materials toxicity.

Wider glaze working temperature range, as they have no defined melting points.

The purpose of the frit production process, usually known as fritting, is to obtain a vitreous material that is insoluble in water by melting and subsequent cooling of the mixture of different materials.

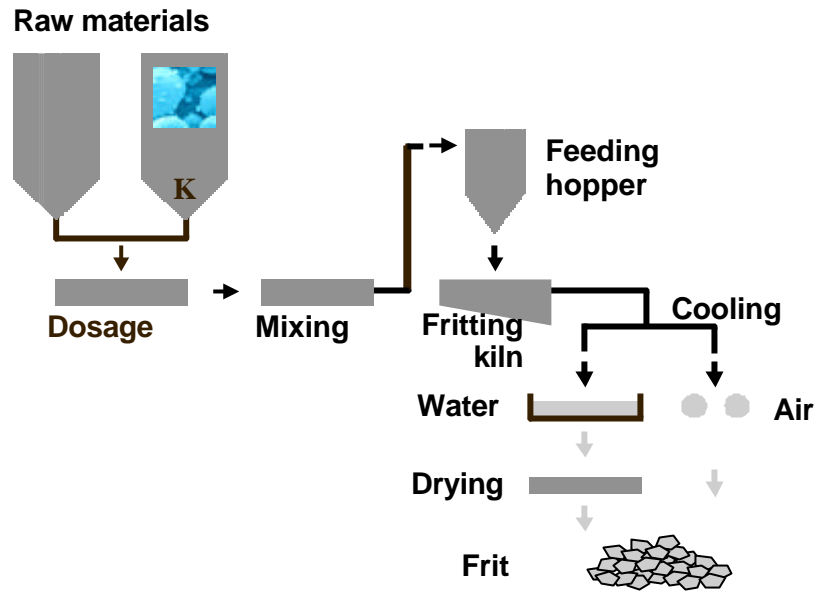


Figure 4. Fritting process

The process starts by proportioning the raw materials that have been previously selected and controlled. The different raw materials are then conveyed pneumatically to a mixer (Figure 4).

A wide variety of frits is available, differing in chemical composition and related physical characteristics. As indicated above, the components that in themselves are soluble or toxic are always provided in fritted form to significantly reduce their solubility. This is the case with lead, boron, alkalis, and some other minor elements. The rest of the components can be used in fritted form or as a crystalline raw material, depending on the desired effect.

Frits can be classified according to very different criteria: in terms of their chemical composition (lead, boric, et.), physical characteristics (opaque, transparent, etc.), melting range (fluxing, hard), etc. A range of frits has been developed for specific manufacturing processes, featuring various concrete characteristics, thus making it even harder to classify ceramic frits.

The raw materials mixture is conveyed to a hopper that feeds it into the fritting kiln by means of an auger, whose speed controls raw materials mass flow into the kiln. The material's residence time inside the kiln is defined by the raw materials melting rate and melt flowability.

The kiln is fitted with natural gas burners, using air or oxygen as an oxidising agent. These systems allow reaching the required temperatures of 1400-1600°C for this process.

Before exhausting the combustion gases through the stack, they are led through a heat exchanger to recover energy for combustion air pre-heating.

The fritting process can be run non-stop with continuous kilns followed by quenching in water or air-cooling, or in rotary batch kilns followed by quenching in water.

Continuous kilns have a tilted base to facilitate the descent of the molten mass. An overflow is fitted at the outlet, together with a burner that heats the viscous frit melt to prevent sudden cooling on contact with the air, facilitating continuous emptying of the kiln.

The melt can be cooled by:

Water. The molten material is quenched on falling into the water. The resulting thermal shock makes the glass shatter into small irregular fragments. These are removed from the water by an auger and subsequently conveyed to a dryer to eliminate any remaining moisture from quenching.

Air. In this case, the molten mass is drawn between two cylinders, fitted with internal air cooling, producing a very fragile sheet that breaks up readily into small flakes.

The batch process is used to produce frits for which there is less demand. In this case, the materials are melted in a rotary kiln, usually followed by quenching in water, these being the only differences from the continuous process.

The rotary kiln consists of a steel cylinder lined with refractory material, which rotates to homogenise the molten mass. A burner is located at one end of the kiln, with the flame facing into the kiln.

The arising gas emissions during continuous and batch melting processes contain gaseous compounds from combustion, gases from the volatilisation of the raw materials feed, and particulates drawn along by the combustion gases exiting the kiln. It is important to note that the composition of these particulates is similar to that of the frit being produced.

Glazes: Preparation and application. Decoration

In the glaze preparation process, the frit and additives are usually ground in alumina ball mills until a preset reject is obtained. The conditions of the aqueous suspension are then adjusted. Suspension characteristics will depend on the application method to be used.

Ceramic tile glazing is done continuously. The most common application methods used in tile manufacture are by waterfall glazing, spraying, dry glazing or decorating.

Screen-printing is the most widespread tile decorating technique, due to the ease of this application in the glazing lines. The technique is used in single, twice and third firing, and it consists of printing a given design by means of one or more printing screens (tensioned fabric with a set mesh aperture). The screen surface is masked, and the printing ink is only put through the openings of the design to be reproduced. When the squeegee crosses the screen it presses the printing ink through the openings left in the screen, thus printing the design on the tile.

Firing

Firing is one of the most important tile manufacturing process stages as most tile characteristics depend on it. These include mechanical strength, dimensional stability, chemical resistance, cleanability, fire resistance, etc.

The main variables to be considered in the firing stage are the thermal cycle (temperature-time, Figure 5) and kiln atmosphere, which must be adapted to each composition and manufacturing technology, according to the ceramic product to be made.

Firing cycle

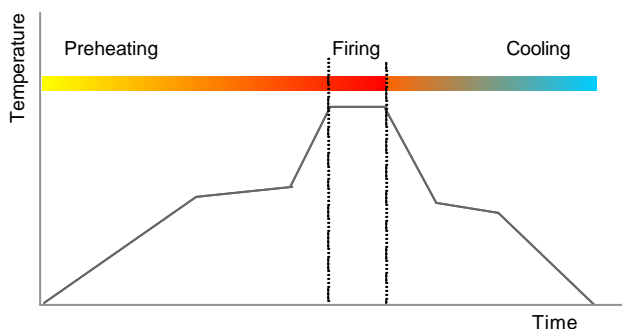


Figure 5.

In the firing operation, the tiles are subjected to a thermal cycle during which a series of reactions take place in the piece, generating changes in the microstructure and providing the desired final properties.

Single and twice fire

Ceramic materials can undergo one, two or more firings. The unglazed ceramic tiles are fired once; glazed tiles can be fired once after applying the glaze to the green tile (single-firing process), or the body may be fired first, followed by glaze application and subsequent second firing (twice-fire process).

There may sometimes be an additional drying stage after glazing. This occurs just before the material is placed in the kiln to reduce tile water moisture content to low enough levels for the firing stage to be carried out properly.

Fast firing

This is currently the prevailing ceramic tile firing method and is done in single-deck roller kilns. It has contributed to reducing firing schedules to less than 40 minutes, due to the heightened coefficients of heat transmission to the tiles, as well as their uniformity and flexibility.

In the single-deck roller kilns, the tiles travel over rollers and the heat required for firing is provided by natural gas–air burners fitted at the sides of the kiln. The main heat transmission mechanisms are convection and radiation. (Figure 6).

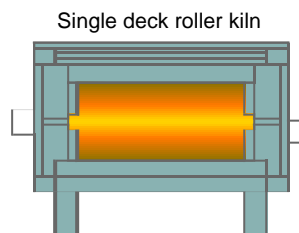


Figure 6.

As non-muffled kilns are involved, gas comes into direct contact with the tiles. This heightens the heat transmission coefficients, reduces the firing cycle and energy consumption and increases kiln flexibility compared to the kilns that were formerly used.

The hot gases that arise in firing are released into the air by two emission sources. On the one hand there are the gases from the preheating and firing zone, which are exhausted via a stack at the kiln entrance and the gases from the cooling zone, which are exhausted via a stack at the kiln exit.

The gases from the preheating and firing processes are mainly composed of substances from combustion and pollutant gaseous components from raw materials decomposition and suspended dust particles. The gases from the cooling stage consist of hot air and can contain dust particulates.

Additional treatment

In some cases, particularly in porcelain tiles, the fired tile surface is polished to produce a shiny unglazed homogeneous tile.

Sorting and packing

The ceramic tile manufacturing process ends with sorting and packing. Sorting is done by automatic systems with mechanical equipment and tile surface inspection. The result is a controlled product with regard to dimensional regularity, surface appearance and mechanical and chemical characteristics.