# The Drying of Clay Based Ceramics

A comparison of air-drying and drying using superheated steam.

By:

Michael C. Connelly

## INTRODUCTION

Ceramics are a valuable and important engineering material in today's world and have been with us for thousands of years. Ancient peoples knew of the useful properties of ceramics and utilized them in the fabrication of pottery, statuary and building materials. In the modern world, ceramics are all around us. Like the ancients we use them for pottery, statuary and building materials, but also for a host of other products such as electrical insulators, heat shields, medical applications and dental implants to name a few. Though new uses and formulations have been discovered for ceramics, two factors have remained constant. Those two factors are the necessity to thoroughly dry the ceramic before its final firing and the use of clay as an important raw material in ceramics.

## CERAMICS

A useful definition of ceramics is the use of inorganic nonmetallic materials, clay being and important example, as an essential component in the fabrication of solid articles. There are many uses for ceramics and many examples of ceramic products including pottery, porcelain, bricks, structural clays, abrasives, cements, glass, glass ceramics, non-metallic magnetic materials, ferroelectrics, and single crystal materials. The uses for ceramics are many and continuously expanding, making ceramics an important engineering material.

There are many types and formulations of ceramics, but they generally all have the same basic mechanical characteristics. Ceramics typically are brittle with little or no deformation before fracture. They have high shear strengths and therefore are not ductile. Also, high hardness and high compressive strength are characteristic of ceramics.

There are various methods of processing ceramics, but the mode that this paper is concerned with is the process wherein ceramic powders are mixed with a binder or a liquid. One of the most often used binders is clay and one of the most often used liquids is water. The process is fairly simple. The clay and water are mixed with the various ceramic components needed for the desired characteristics required in the finished ceramic product. The mixture is then molded or formed to the requisite shape and then allowed to dry. The drying is needed to remove as much water as possible from the ceramic piece before it is fired. Firing is done at higher temperatures than drying and causes the binder and included ceramic powders to fuse and gain strength. The ceramic then can be glazed or otherwise finished. The drying procedure is vital, since if not all the water is removed, upon firing, the water may turn into steam, expand, explode and destroy or damage the ceramic.

## CLAY

The extensive use of clays as binders in the production of ceramics, is due to the fact that clay-water mixtures are plastic. Plasticity allows clay to be molded easily and permits the holding of these molded shapes. Also, clay is cheap and readily available. Clays can be generally characterized as fine particle hydrous aluminum silicates. Kaolinite, $AL_2(Si_2O_5)(OH)_4$, is one of the most common types of clay used in the ceramics industry and of the most interest in this discussion and depicted in Fig. 1, which displays the typical layered crystalline structure of clays. The layers are electrically neutral, allowing them to slide on each other, giving clay a soft soapy feel and allowing easy cleavage.

In the ceramic fabrication process, clay is mixed with water to form a colloidal suspension. The clay is mixed with the water in such proportions that the suspension is stiff enough to be molded and retain the molded shape. As is obvious, there is much water used in the process as a plasticizer. Water is adsorbed on kaolinite crystal edges and held there by weak Van der Waals forces on the surfaces of the clay particles.(Fig. 2) There is water on the surface of the ceramic, in capillaries, in pores and also present is forming water which causes separation of the particles. In addition to this water mechanically added by the mixing of the clay-water mixture there exists within the clay particles themselves, molecules of water in the form of Hydroxls held there chemically by hydrogen bonds.

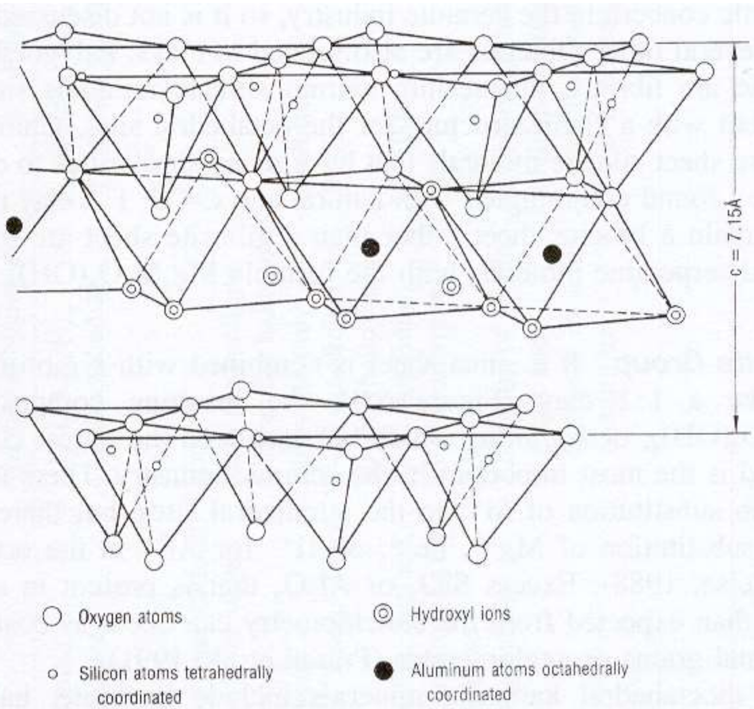


**Figure 5.9** Idealized structure of kaolinite (from Pickering and Murray, 1994; courtesy of the Society for Mining, Metallurgy, and Exploration (SME), www.smenet.org).

Fig. 1 (From Stinton, 2006)

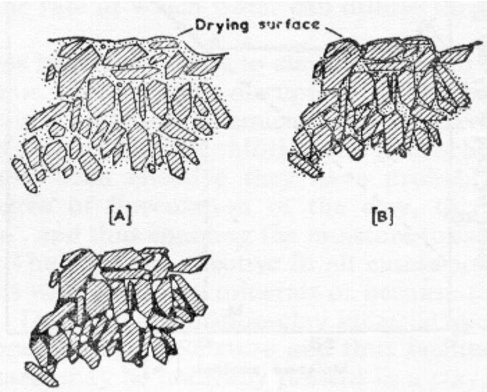


FIG. 59. Behaviour of clay particles on drying.

Fig. 2 (From Worrall, 1975)

<u>DRYING OF CERAMICS</u>

The major thermodynamic process involved with the drying of ceramics is simply evaporation. Heat is applied to the ceramic product heating it, and also heating the water contained inside the ceramic and upon its surface. The water attains a temperature at which it makes a phase change from liquid to water vapor. The heat initiates the evaporation process and also breaks down the hydrogen bonds in the clay molecules releasing the hydroxls as water as well as breaking the weak Van der Waals bonds holding the water on the surfaces of the clay particles.

As drying occurs adsorbed liquid films contract and surface tension forces draw the clay particles tightly together. The clay particles are brought very close together as the last of the water is removed and any repulsive electrostatic forces that were present are extinguished leaving only attractive Van der Waals forces between the clay molecules. A great dry strength is the result of this process.

However, if the evaporation or drying rate is too high, problems can result. Shrinkage is common during the drying process as water is removed. If the shrinkage is too rapid, cracks often develop in the drying surfaces of the ceramic. Also, if the drying is not even throughout the volume of the part, the quality and the homogeneity of the ceramic will suffer. If the surface dries first, it will shrink first and the pores and capillaries will tighten and close, making it much more difficult for internal water to escape by evaporation and capillary action. As a result the drying rate will slow and prolong the drying process.(Figs. 2-4)

Viscosity of the clay-water mixture as well as the viscosity of the water by itself will affect the drying rate of the ceramic. The more viscous the clay-water mix is, the less water there will be present to be removed from the formed product. The more viscous the free water, or water in the capillaries and pores, the easier it will rise through capillary action and out of the drying ceramic. Heat will lessen the viscosity of this water and aid in removing it while the viscosity of the clay-water mixed can be controlled by proper mixing at the beginning of the process.

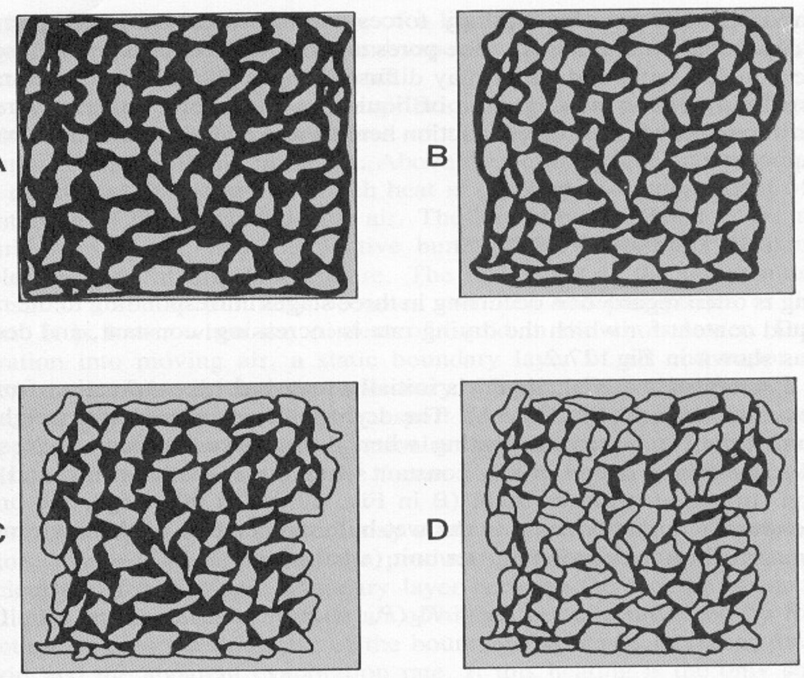


**Fig. 27.3** Distribution of liquid among particles during slow drying: (A) as cast, (B) just preceding the end of the constant rate period, (C) entering the falling rate period, and (D) near the end of the falling rate period.

Fig. 3 (From Reed, 1995)

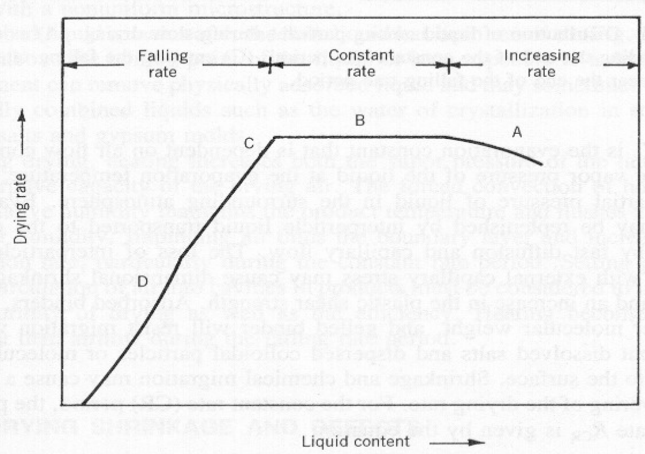


**Fig. 27.2** Change in drying rate when drying a product under moderate conditions. The letters on the diagram correspond to those in Fig. 27.3 and discussion in the text. Point C corresponds to the end of shrinkage in all regions only when the liquid is uniform throughout the volume of material.

Fig. 4 (From Reed, 1995)

## AIR-DRYING VERSUS SUPERHEATED STEAM

There are several methods for the drying of ceramic materials, but this paper will focus only on air-drying of ceramics and the use of superheated steam for drying. Air-drying is the circulating of hot, dry air over the surface of a ceramic. Such a system can be as simple as bricks drying outside in the sun or can be the drying of materials in a closed oven with circulating hot air. The hot air passes over the surface of the ceramic causing evaporation of water at or near the surface to occur, as well as some water removal through capillary action.(Fig. 5) As this drying takes place, the clay particles shrink, causing them to draw closer together due to the surface tension of the water in the capillaries of the ceramic. The surface tension also increases as the diameters of the pores and capillaries become smaller allowing water to evaporate and flow out from deeper within the ceramic.

The ceramic, in this process will dry from the outside in, since the piece is not of uniform heat when the evaporation begins. The heat of the hot air is not transferred uniformly throughout the volume of the part. This can lead to cracking during shrinkage if the evaporation is too fast, and also to the parts being non-uniform throughout their volume.(Figs. 2&3) Also, the shrinking of the surface layer makes it more difficult for internal water to rise to the surface since the clay particles are drawn tighter together at the surface which will result in a slowing of drying rates.(Fig. 4) This condition can lead to extended drying times and greater consumption of energy due to the heating of more air.

Drying with superheated steam is also know as airless drying and is done in a sealed chamber. The ceramic part is placed in the dryer and completely heated to near 100 C° before the evaporation process is allowed to start. Some water will evaporate out of the part and become steam. Extra steam can be added if it is needed as well. The steam atmosphere is permitted to increase until the dryer atmosphere achieves saturation. Air and excess steam are vented to maintain atmospheric pressure in the dryer itself. This vented steam can be reclaimed as distilled water for later use. When the dryer atmosphere becomes saturated the evaporation of the water in the part begins. The heat that the steam provides evaporates the water in the ceramic. The superheated steam drying process and a typical airless drying cycle are illustrated in Figure 6.

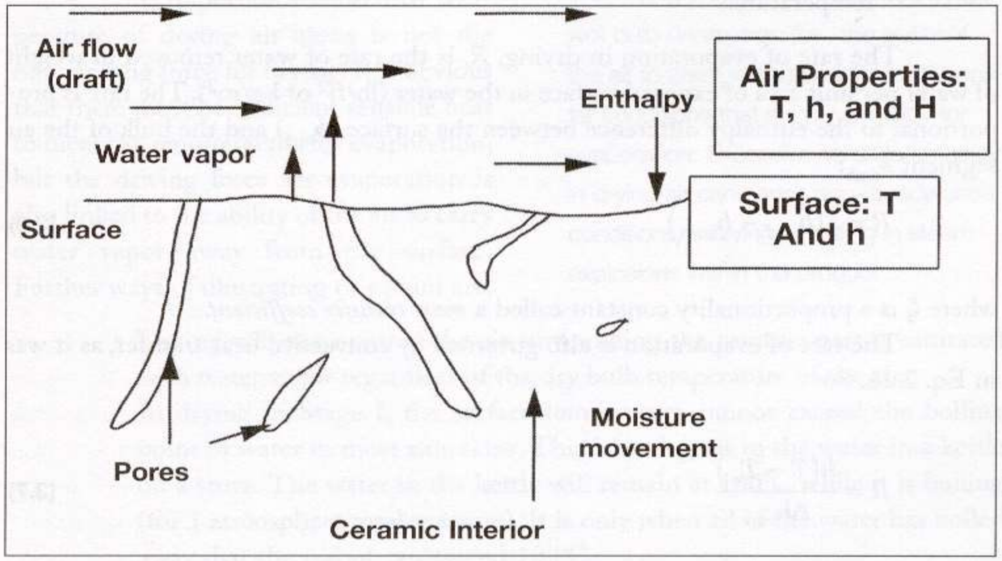


**Figure 3.5:** Model of cross section of a drying ceramic.

Fig. 5 (From Brosnan, 2003)

8.9 Introduction

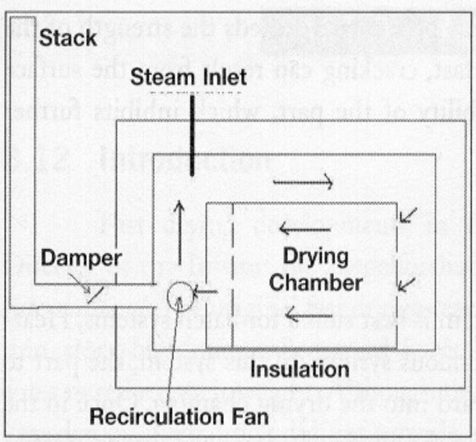


**Figure 8.5:** Schematic of airless dryer.

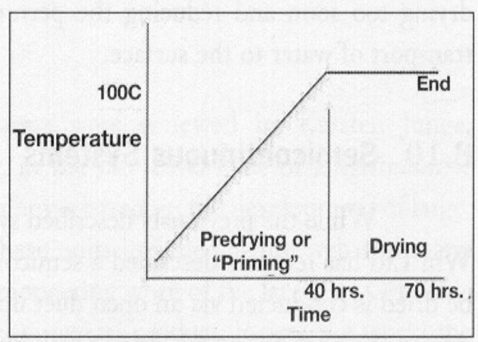


**Figure 8.6** Typical airless drying cycle.

Fig. 6 (From Brosnan, 2003)

Drying with superheated steam does have some definite advantages over drying ceramics with hot air. The saturated steam atmosphere transfers the heat more efficiently to the part than dry, hot air does. Superheated steam has a higher heat capacity and much higher heat transfer quotient than does dry air making the steam a much better drying medium. By heating the part completely before evaporation starts, the process allows the ceramic to dry evenly throughout its volume at the same rate. The outer surface does not dry and shrink first, thereby slowing the drying of the interior. The evaporation rate is better controlled as is the drying rate, which results in a more uniform ceramic and fewer cracks due to shrinkage.

Drying with superheated steam is also more efficient in usage of energy and time than is air-drying. Enthalpy loss for superheated steam drying systems is less than for dry air systems. Enthalpy can be defined as recoverable or exchangeable energy. As applied to ceramic driers much of that energy is in the form of heat. For a dryer the difference between the enthalpy of the hot supply and the dryer exhaust is called the dryer loss. One hundred percent dryer efficiency is achieved when the exhaust air is saturated with water vapor. A dryer using superheated steam, an airless dryer, comes closer to the 100% efficiency and a dryer loss of zero than does a hot air drying system. Less enthalpy, or recoverable energy, is lost with superheated steam since a new air supply is not continuously heated as with a hot air dryer. A hot air dryer loses much energy through heat exhausted after it has passed over the ceramic surface. The superheated system is enclosed and reuses the same steam and heat to dry the part. Any steam that is vented can be recovered as distilled water and used again in the process if desired. The drying cycle is shorter for superheated steam, thereby requiring less energy.

The entropy of a superheated steam system is less than for a hot air dry system since there is less non-recoverable energy when using superheated steam. Non-recoverable energy can be explained in basic thermodynamics as energy expended in the form of frictional losses. The entropy of drying ceramics can be visualized as particle translations or rotations during shrinkage leading to frictional loss. Superheated steam can control the evaporation of the water and the drying rate and thus, the shrinkage of the ceramic and the friction losses caused by the same.

## CONCLUSION

The drying of ceramics using dry, hot air is an ancient method that has worked for thousands of years. It is a tried and true system that is effective. The use of superheated steam for drying ceramics is a comparatively new technology that has definitely improved the way that ceramics can be dried. A superheated steam dryer use less energy, loses less energy, controls the drying process more efficiently and produces a more uniform ceramic. Perhaps the only advantage that a hot air dryer has over a superheated steam dryer is lower cost, since in some cases all one needs to air dry ceramics is the sun.

## REFERENCES

(1) Denis A. Brosnan and Gilbert C. Robinson, Introduction to Drying of Ceramics: With Laboratory Exercises, The American Ceramic Society, Westerville, Ohio, 2003.

(2) Kenneth G. Budinski, Engineering Materials: Properties and Selection, Second Edition, Reston Publishing Company, Inc., Reston, VA, 1985.

(3) David J. Green, An Introduction to the Mechanical Properties of Ceramics, Camridge University Press, Cambridge, 1998.

(4) W. D. Kingery, H. K. Bowen and D. R. Uhlmann, Introduction to Ceramics, Second Edition, John Wiley & Sons, Inc., New York. 1976.

(5) Merle C. Potter and Craig W. Somerton, Schaum's Outline of Thermodynamics For Engineers, Second Edition, McGraw Hill, New York, 2006.

(6) James S. Reed, Principles of Ceramics Processing, Second Edition, John Wiley & Sons, Inc., New York, 1995.

(7) Christopher W. Sinton, Raw Materials for Glass and Ceramics: Sources, Processes, and Quality Control, John Wiley & Sons, Inc., New York, 2006.

(8) Lawrence H. Van Vlack, Elements of Materials Science and Engineering, Fourth Edition, Addison-Wesley Publishing Company Inc., Reading, Mass., 1980.

(9) W. E. Worrall, Clays and Ceramic Raw Materials, Halsted Press, New York, 1975.