Firing Dental Ceramics
Introduction

The condensed ceramic, described at the end of the last topic, is first dried then fired to obtain its full strength. The **drying stage** involves the removal of the remaining water from the ceramic paste resulting in the green strength of the compact.
Introduction
The **firing stage** occurs after the drying stage and involves a series of processes. The compact is heated to temperatures around 900°C. During this firing the powder particles gradually fuse together going through the processes of **boundary elimination** and **lensing** of the voids.
Introduction

The **final firing stage**, at the final temperature, can control the final product. The time and temperature, over-firing and under-firing and the use of vacuum can all affect the end ceramic. These factors can change the ceramic strength, porosity levels, dimensions and also the way the ceramic processes light. The passage of light through the fired ceramic crown needs to duplicate the way natural tooth material processes light.
The Drying Stage

Drying is carried out by slowly heating the compact to a hundred degrees or more. This is done with the aid of the programmable furnace so that all the water which remains between the particles is removed by gently vaporising it.
The Drying Stage

This leaves the particles held together by small points of the **organic gum**, as shown in the diagram. This is very similar to the last diagram in the previous topic, except that the film of water has been reduced to a gum patch. The gum will not be destroyed until the temperature exceeds 250°C.

*Diagram: Ceramic particles held together in the “green state” after all liquid has been dried off*
The Drying Stage

If drying is carried out as a separate procedure from the beginning of firing, it must be remembered that the compact will have very little strength until the first stages of particle bonding begin at 800°C or thereabouts. After condensing, and drying, the compact is only held together by a little gum.
The Drying Stage

Its **green strength**, as it is called, is so small that the ceramic can easily be removed from the substrate by a knock. If drying is too rapid, for example, the pressure of the water escaping as steam can literally blow the ceramic powder from its substrate.
The Drying Stage

After drying, the ceramic is fired. It is heated until the glass becomes soft enough to flow slightly. At this temperature the diffusion of atoms across the contact points where the particles meet will gradually remove the boundaries between particles. The compact will become one piece.
The Drying Stage

The next diagram shows the structure obtained after the boundaries (shown by dotted lines) have been eliminated. This can be called **the elimination of boundaries**.
The capacity for atomic diffusion, which will become significant enough to eliminate boundaries in dental glasses at 800°C or more, will also be accompanied by a substantial decrease in viscosity of the glass particles. They become able to flow gradually at such a temperature. This is a dental glass flow.

The Drying Stage
The Drying Stage

This lower viscosity of the ceramic not only helps the particles to bond together at their boundaries, it also assists in the gradual removal of porosity. As can be seen in previous diagrams, joining the particles together at contact points still leaves considerable gaps in the regions where the particles do not touch. This is why good condensation technique is so important. It will minimise the size of these gaps. There is a bonding of ceramic particles where the boundaries are eliminated.
The Drying Stage

These gaps between particles become porosities. At the same time, the viscosity of the glass is low enough for it to flow in response to its own surface tension. A spherical volume of material has less surface area than any other shape, so it takes less energy.
The result is that the porosity voids will gradually become rounded as firing proceeds, as shown in the next diagram.

The Drying Stage

Lensing, or rounding of voids as sintering of the soft glass proceeds
The Drying Stage

This process is called **lensing** because the rounded voids begin to take on a lens like shape. Void rounding increases the strength of the ceramic compact (voids with more pointed shapes produce high stress concentrators, like internal notches or cracks).

*Lensing, or rounding of voids as sintering of the soft glass proceeds*
The Drying Stage

Ceramic particles held together in the “green state” after all liquid has been dried off

Boundary Elimination

Lensing, or rounding of voids as sintering of the soft glass proceeds
The Final Firing Stage

As firing proceeds, the voids slowly rise to free surfaces and disappear. However, this takes longer than a typical firing cycle. Unfortunately the flow of the soft glass which will eliminate the pores also causes the ceramic to slump. If we wait long enough at firing temperature to eliminate porosity, the same mechanism will eliminate the shape we made and leave a globule of ceramic.
The Final Firing Stage

The presence of leucite helps to reduce this slumping effect, but it cannot be totally avoided. Consequently typical dental ceramics retain a considerable amount of porosity (from 10 to 30% would be quite normal).
The Final Firing Stage

Time and Temperature (cont’d)
Increasing the firing temperature speeds up the sintering, lensing and void removal processes, as does increasing the firing time. Increasing the temperature has a proportionately greater effect than increasing firing time.
The Final Firing Stage

Time and Temperature

Several properties of the fired ceramic depend on careful control of the firing cycle. As the diagram below (next slide) shows, the strength of a fired dental ceramic is developed only when the boundaries are eliminated. Firing at 50°C below the correct temperature can reduce the flexural strength by 40%.
The Final Firing Stage

Strength of the sintered compact

Temperature

Correct firing temperature
The Final Firing Stage

Over-firing and Under-firing

Firing at above the correct firing temperature will sometimes reduce the strength, depending on the particular ceramic. The formation of undesirable crystal phases at higher temperatures, or de-vitrification is one possible reason. In any event, **over-firing increases the chances of slumping**. Also, a longer firing time results in over-firing the ceramic.
The Final Firing Stage

Over-firing and Under-firing (cont’d)

Boundary elimination and the beginning of porosity reduction involve the reduction of space between particles. This will also produce an overall shrinkage of about 25% in the dimensions of the ceramic compact after exactly the same time and temperature.
The Final Firing Stage

Over-firing and Under-firing (cont’d)

At the same time that the compact is sintering, the elimination of boundaries has other effects. Because light is reflected and scattered at boundaries between particles and at the surfaces of porosity voids, **under-fired compacts will have a chalky white colour overlaying their shades.** The full development of the translucent shade will only occur at the correct firing temperature.
The Final Firing Stage

Glazing

The presence of flow in the ceramic particles also allows the development of glaze layers. In self glazing, use is made of the fact that ceramics are very good insulators. Because of this property, the outside temperature of the compact is higher than the inside. As a result, if firing is allowed to proceed long enough, the outside layers will slump and run before the inside layers do. If firing is stopped at this point, the runny surface will produce a glaze.
The Final Firing Stage

Glazing (cont’d)

Alternatively, a glaze can be produced by a separate firing. The compact is removed from the furnace after it has been fired once, and a thin layer of a glass with a lower fusing temperature painted on to it. This layer will sinter and then run at a temperature lower than that which would cause slumping in the existing ceramic layers.
The glaze layer can be used to carry any *cosmetic staining* which becomes necessary by painting such stains onto the surface and re-firing.
The Final Firing Stage

Reduction of Porosity

Porosity considerably reduces the strength of a sintered ceramic, so considerable efforts have been made to minimise it.
The Final Firing Stage

Vacuum Firing

Applying a vacuum to the compact as it is heated up to firing temperature will remove air from the gaps between the particles. It is important to apply the vacuum before the particles start to sinter together, so that the air can escape along boundaries. The absence of air in voids at firing temperature does not greatly assist their removal, but it does speed up the rounding of the average void shape.
The Final Firing Stage

Vacuum Firing with Air Pressure

The effect of firing under vacuum in reducing porosity is considerably increased if the air pressure is restored while the compact is still at firing temperature. The external air pressure is transmitted throughout the soft glass, and the voids, which have a very low air pressure within them, are collapsed to an acceptable extent, becoming smaller.
The Final Firing Stage

Diffusible and Compressible Gases
If the firing chamber is filled with a diffusible and compressible gas, it will find its way into the voids, and allow subsequent air pressure to collapse them in a similar way to the use of air and vacuum.
The Final Firing Stage

Bonding of Crystalline Particles

The coloured particles, which make the shades; the alumina particles, which help reinforce opaque layers and aluminous porcelains; the whitish tin oxide particles which produce the opacity of opaque porcelains, and the leucite which reinforces the glass against slumping are all crystalline material.
The Final Firing Stage

Bonding of Crystalline Particles (cont’d)

They are not softened at the firing temperature of the ceramic they are added to. However, they are still at a high enough temperature to have rapid diffusion of atoms into the glass particles, and rapid diffusion of the atoms from the glass particles into them. As a result they become fully bonded into the sintered glass structure.
Some Additional Materials that can be Fired

Metal Corrector
  Fires around 1100°C
  A Metal powder
  Sintered

Shoulder Porcelain
  Fired post opaque
  Final correction at glaze

Correction Porcelain
  Low Fusing
  Fires below glaze temp.
  Poor aesthetics
  Can be mixed with ceramic powders