PART II Clay and 3D printing

Cutting clay with a wire tool

Clay is a natural material, which comes from soil and has been used for thousands of years to make different kinds of objects - from dishes, to vases and sculptures.

We can define two different types of clay: primary and secondary.

Primary – the clay that is found in the same place that it formed:

Kaolin: A fine, white, very pure, and infusible China clay, almost pure alumina and silica. Mainly used in the manufacture of porcelain and fine earthenware.

Secondary / sedimentary – the clay that has been eroded by the river or the movement of the earth and then deposited in different layers:

Ball Clay: 20-80% kaolin, 10-25% mica, 6-65% quartz It's used in a percentage between 10 and 20% to improve the plasticity of the clay

Refractory: a refractory material retains its strength at high temperatures. ASTM C71 defines refractories as "non-metallic materials having those chemical and physical properties that make them applicable for structures, or as components of systems, that are exposed to environments above 538 °C. Refractory materials are used in linings for furnaces, kilns, incinerators and reactors. They are also used to make crucibles.

Stoneware: due to its high strength and durability, stoneware has a wide range of uses, including: hotelware, kitchenware, cookware, garden products, electrical, chemical and laboratory ware. Formulations vary considerably, although the vast majority will conform to: plastic fire clays 0 - 100% , ball clays 0 - 15%, quartz 0 - 30% feldspar and chamotte 0 – 15% Biscuit firing is around 900°C and glost firing 1180 - 1280°C. Water absorption of stoneware products is less than 1%

When 3D printing as well as traditional clay modelling, we have to choose the correct clay according to our application. The main difference between clays is the **firing temperature**, that comes from their individual compositions. Depending on the desired application and on the kiln being used, we have to choose the correct clay for the project.

Low firing clay: red clay, white clay, egyptian clay

High firing clay: stoneware, porcelain or paperclay.

The best clay for our application also depends on other features like plasticity, shrinkage or porosity.

Plasticity: it is the property of the clay that defines its ability to be able to resist cracking when bent, dependent on the mix and ratio of the basic components of the clay (chamote, ball clay, kaolin etc.)

Plastic clay

Less plastic clay

In case of 3D printing, it is better to use clay with good plasticity to avoid cracking during the drying period.

Shrinkage: it depends on type of clay and the quantity of water inside the mix. Around 5-10% for red clay and 10-20% for porcelain.

Porosity: it depends on the type of clay and defines the clay's ability to absorb liquid after firing, which is important when applying glazes.

In this book we use the DeltaWASP 2040 Clay 3d printer that needs a relatively soft clay - at time of writing there are other 3d printers from WASP as well as other other companies that can print using harder clays.

Mixing

The process starts from a common block of commercial clay, adding some water to mix and make it softer. Usually the final proportion is 5% liquid. E.g. 950g clay 50g liquid. Some people prefer to add alcohol/ethanol instead of water, because alcohol evaporates quickly and helps clay support its own weight during the printing process. During the mix, - done either by hand or with a mixing machine - the main issue is to avoid incorporating air bubbles in the paste. In order to prevent air bubbles remaining in the mix, it is possible to throw the paste on the floor to make the bubbles explode without damaging the clay.

Air bubbles are one of the most common issues encountered during 3d printing because they can change the material flow or create small air craters in the printed object, which can leave lumps or burst marks.

Air bubble during the mix.

Extruding

The clay goes inside the clay's deposit in clay balls. Pushed by an air compressor or any other system, it goes into the extruder to be shaped with the correct flow according to our 3D design.

WASP extruder.

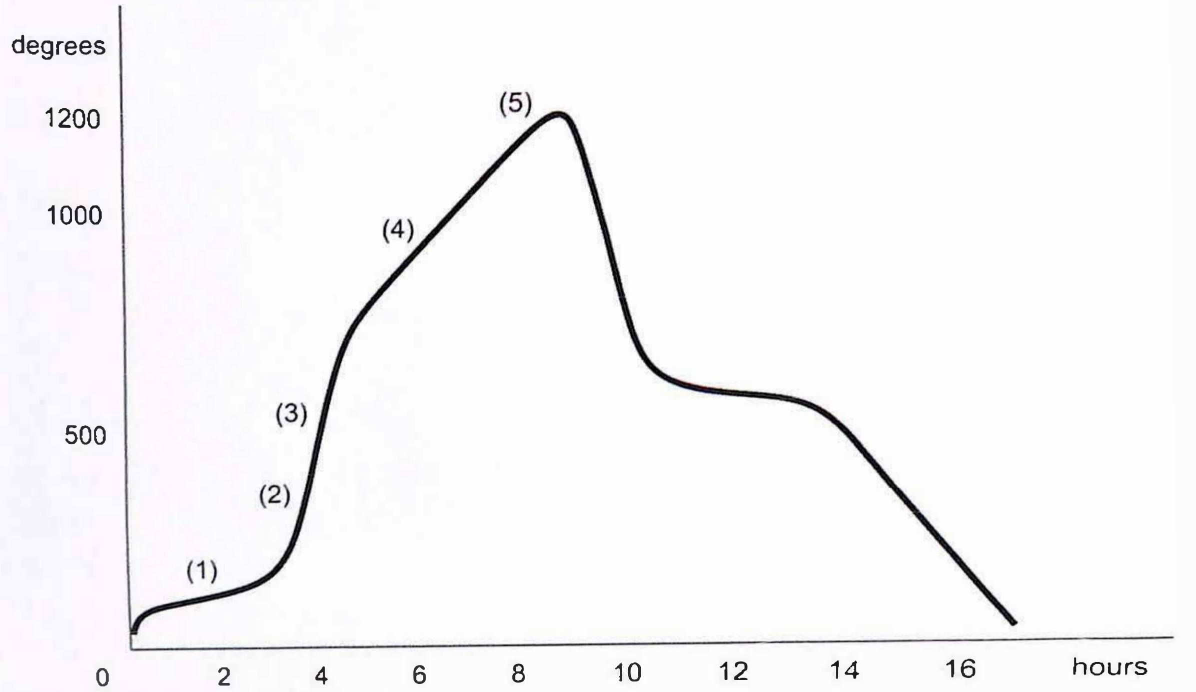
Firing

Firing is one of the final stages involved but it is also one of most complex parts. Before firing it is important to properly dry the object. Clay is composed of almost 25% water. it is very important to dry slowly, to prevent shrinkage & cracking during the air drying and air bubble explosions during firing. The firing is usually controlled by an electronical kiln controller that sets a heating curve for 'hight firing clay' divided into steps:

(1) Drying: at this stage the temperature is set at about 100° to boil the water, usually taking almost 2 hours but it could be even longer in order to guarantee the prevention of shrinkage.
(2) Dehydration: at 350° this is the point where the chemically combined water of the clay evaporates.
(3) Quartz inversion: it happens at 573°. At this point, quartz crystals rearrange themselves into a different order.

(4) Biscuit: 900° the clay is fired but not completely vitrified. It is porous. If the piece is going to be glazed, this is the stage to stop firing.

(5) Vitrification: it is the hardening and partial glassification of the clay, which depends on its composition, for example red clay will vitrify at about 1000°, porcelain at about 1250°.



Due to the diminishing size of the particles, shrinkage mainly happens during the vitrification stage and the overall size can decrease between 8% and 13%.

Melting: A dangerous stage that should be avoided, melting occurs if the firing temperature exceeds that in the reported datasheet, as the clay will melt and this cannot be reversed.

Glazing

After firing comes glazing, but that is a task already covered by many specialized books.

In the picture, 3D printed parts in the kiln ready to be fired.