CERAMICS

Claimed to be man's oldest industry - still one of outstanding importance to-day.

What is meant by "Ceramics" - basically pottery, but includes all those products (and their manufacture and the raw materials) which use clay or similar plastic material, and after shaping use a firing process to produce mechanical strength.

One usually thinks first of domestic pottery; - porcelain, china and earthenware. Apart from the utilitarian aspect of this branch of ceramics, it is here that man has shown himself to be an artist. One associates beauty, elegance and colour with much of domestic pottery, whether ancient or modern.

Other important branches of ceramics are:

- bricks and tiles: a massive industry in many countries
- refractory materials: for furnaces, etc.
- sanitary engineering components: drains, lavatories, sewage, etc.
- chemical vessels, etc.
- electrical insulators

Some of these, naturally, have a somewhat limited history.

Before discussing the history of ceramics, we must consider the nature of the materials, processes, and products.

Two types of finished ceramic ware:

(a) permeable (b) impermeable

This refers to the body material and ignores any glaze.

Permeable ware shows a rough fracture, sticks to the tongue, and absorbs water. Includes

(i) heavy clay ware - bricks and tiles, etc.

(ii) refractory ware

(iii) terra cotta: unglazed ware, fired at relatively low temperature therefore rather soft and porous. Yellow to brown.

(iv) earthenware: glazed ware, fired at higher temperature and harder than terra cotta. White or ivory.

N.B. "Faience" and "Majolica" are special kinds of glazed earthenware, but their definitions vary. Generally faience is tin-enamelled earthenware, majolica is particularly the Italian version of it.

Impermeable ware is dense and non-porous, having been fired at a much higher temperature so that vitrification (i.e. fusing) has taken place. Includes

(i) stoneware: not translucent, grey or brownish body

(ii) vitreous china: similar, but white

(iii) porcelain and china: translucent and white

The raw material: CLAY (N.B. Alumina and other materials are nowadays also used for specialized ceramics)

Clay is produced by the decomposition of feldspar, and feldspar is the most abundant material found in crystalline rocks. $\frac{3}{4}$ of the surface of the earth is granite and gneiss, and these are 60-90% feldspar. The other components are quartz and mica. The decomposition is due to the action of CO_2 and water. Clay is $Al_2O_3.2\ SiO_2.2H_2O$, or by weight

46.3% SiO_2; 39.8% Al_2O_3; 13.9% H_2O.

This is pure clay. Impurities occur with it in nature. Clay is plastic because of the small size of its particles (among other things).

Kaolin or china clay has particle size < 0.01 mm diam.

Ball clays have even smaller particles, and are more plastic.

When clay is required, not as a stiff paste, but as a cream-like liquid "slip", a small amount of alkaline solution is added.

The effect of drying clay (e.g. after an article has been shaped) is this: clay crystals (however minute) are sheet-like. When wet, they slide about over one another, but are hard to pull apart - hence the plasticity - because of the electrical forces of the ions present in the watery solution. As the material is dried, the lubricant between the crystals disappears and the crystals stick together. During this stage the clay shrinks. As the rest of the water dries out there is no further shrinkage.

The effect of firing. Chemically combined water is evaporated by 450-500°C.

Above 600°C or so there is further shrinkage as the crystals begin to fuse together and so give mechanical strength. There is no definite melting point for clays, but we can say in loose terms that it is about 1770°C.

Pure clay is rarely used In order to get a proper mix of all constituents, the materials have to be broken up. Clays are left to weather, and are

broken up in the dry state by mechanical crushers - e.g. roller mills. Materials added to clay are calcined flint, sand, glass, which can greatly affect the properties of the fired ceramic since they are fusible at temperatures around 1000°C. - and these materials have to be milled too. Then mixing takes place in suitable mills, either of the dry materials, or of the clay slip (i.e. made into solution).

Shaping of clay

"Throwing" is the best-known and a very old process. Lump of plastic clay put on spinning wheel and shaped by the potter's hands.

Moulding. Bricks are moulded-formerly by hand, now by machine. (wooden moulds)

For pottery, Plaster of Paris moulds used - does not adhere to wet clay.

Jollying. Partly moulded, partly shaped by profile tool, e.g. cups: outside formed by mould, inside by tool

Extrusion for rods, pipes, etc.

Pressing for mass-production

Turning e.g. for sparking plugs, insulators, etc.

Slip casting: dry plaster mould filled with liquid clay (slip). After a time the liquid is poured out. A clay layer adheres to mould, and when left to harden can be removed, fired and glazed.

Firing. Done in kilns. Usually in "periodic" kilns - i.e. shapes stacked up, fire lit and firing done, kiln cooled and products removed. Then all over again. Inefficient as much heat wasted. So nowadays "continuous" kilns coming into use. These may be of the tunnel type, where the material to be fired in mounted on vehicles or a conveyor, and slowly drawn through the kiln. The centre part is the hottest, so the ware gradually heats up to max. temp., then cools again, but no heat is wasted in alternately heating and cooling the kiln. 1150-1250° for earthen ware. 1400°C for porcelain.

Glazes. In the case of porous ceramics it is often necessary to add a glaze which is itself impermeable and therefore prevents the penetration of water into the body. In the case of non-porous ceramics, a glaze is usually added to increase the smoothness and brilliance of the surface.

A glaze is like a glass: it becomes liquid during the firing. But it must not be too liquid, or it would run off. It is applied to the body (usually) as a suspension of fine particles in water. This then dries, leaving the glaze particles on the surface: firing can then take place. Sometimes the glaze is applied to the unfired body - then there is only one firing. Sometimes the body is fired first, and then glazed in a second firing to a lower temperature. It is important that the temperature coeff. of expansion of glaze is the same as that of body, otherwise it will crack (if coeff.lower) or peel off (if higher).

Glazes comprise a mixture of acid oxide (e.g. silica SiO_2 or boric acid H_3BO_3) and basic oxide (Na, K, Ca oxides, or tin, zinc, etc.) The higher the silica content, the higher the melting point.

For stoneware, a salt glaze is often used. This is obtained by throwing salt into the fire mouth in the later stages of firing.

Decoration

"Under-glaze " colours are applied to the body before firing (i.e. to the "bisque" or biscuit) and then the glaze is applied later. The colours are suitable metal oxides calcined with china clay, alumina, etc. and then ground to a very fine powder and mixed with gum or oils. Can be painted or sprayed, stamped or printed, onto bisque. Dried (if necessary, heated) and then glazed and re-fired (around 1100°C).

"On-glaze" colours are applied after glazing. The colours are mixed with glassy material of low softening temp., mixed with oil and painted on. The article is then fired in the "enamel kiln" to about 750 - 850°C. Not so durable as underglaze, but bigger variety of colours available.

Porcelain Dense, impermeable, white, translucent.

Many varieties, but excluding laboratory and electrical porcelain, there are mainly 3:-

(i) hard porcelain 100% impermeable

(ii) soft porcelain

(iii) bone china $>$ 98% impermeable

Hard porcelain: Kaolin 50%, feldspar (Cornish stone) 25 - 30%, silica or quartz 20 - 25%.

(The feldspar fuses around 1200°C) Fired at 1400°C, gives a vitrified translucent porcelain. Glaze & bisque formed at same temperature.

Soft porcelain: Normal porcelain in Europe before Chinese secret discovered
Contains powdered glass mixed with fine clay. Fired at
Bone China: purely British product. Kaolin 20 - 30%, Cornish stone, 20-32%, Bone ash 27-46%. The plastic material is less plastic than for hard procelain and so requires more careful handling. Fired at 1300°C, then glazed, then fired at 1100°C.

HISTORY OF CERAMICS

Goes back at least 15,000 years. Remains of fired clay vessels found in England, Belgium, Germany, Egypt, the Americas have been dated this far back.

Definite history, as with most of technological history, starts around 5,000 - 3,000 B.C. Before that, only certain knowledge relates to bricks.

Egyptians made terra cotta vases, &c, in red & black, hand modelled.
Tiles with blue copper glaze from 3500 BC.
Glazed earthenware in general around 2000 BC.
Peak reached 1700 - 500 BC. Really outstanding work done.

Babylonia & Assyria. Glazed bricks and ceramic coffins with enamelled surfaces. 9th - 6th cent.BC, wall tiles & bricks decorated in relief & covered with tin glaze.

Persia Very sandy body and ∴ very skilled work in shaping. Brilliant yellow, blue and green glazes. More plastic clay used later. High ornamentation.

India. Very early pottery. Very well developed hand-modelled red terra-cotta vases from N.W. India in third millenium BC.

Greece Developed their own art, highly ornate. Did not use heavy glazes, but rather a slight gloss called "lustre" - technique not now known. Lustre is dark due to iron oxide. Body of the ware is soft, easily scratched, ∴ fired at a low temp. In early work, decoration scratched on, or impressed by metal dies. In the 6th - 4th cent. BC, decoration by "slipping" - i.e. painting with a coloured clay slip - developed.

Roman Empire. Outstanding in the manufacture of bricks and tiles and they carried the art throughout their colonies. At first they used stone for walls and fired bricks for roofing.

Roman pottery of two types - Samian (red) and Etruscan (black & rarer).

Samian ware found in all Roman-occupied areas and of uniform technical characteristics. Made by moulding, with patterns of decoration impressed by the inside of mould. Interior of vessel shaped (in the mould) by a lathe. The glaze was a brilliant gloss and it is not known how it was done.

Romans also made ceramic drain pipes, bath tubs, etc. Vitrefied stoneware pipes with shaped ends for fitting together were very much as we use now. Sanitary pottery reached a high degree of perfection in ancient Rome. With the decline of the Empire, art was lost - emerged again only in 19th cent.

China. Pottery apparently dates from 2698 BC. Reached a high state of perfection according to historians. Note that this period also saw the discovery of the compass, the calendar, ships, mathematics. But no remains found older than 5th cent.BC. These are rather primitive pots, made on potters' wheel, glazed.

Dating from around 100 BC, better developed vessels of a kind of stoneware have been found. Although not white and translucent enough to be really called porcelain, they were very close to it. First real porcelain probably dates from around 600 AD - over a millenium earlier than in Europe! Tea-drinking (reported from 8th cent.AD) encouraged manufacture of fine porcelain.

Ming Dynasty period (1368 - 1643 AD) most famous. Blue and white porcelain with overglaze decoration.

Main centre of Chinese pottery from this time was the pottery town of King-Te-Chin; by 1712 over a million inhabitants. 3000 furnaces.

Japan developed the art later, after getting the secret of porcelain from China in the 13th cent. Famous is the Japanese "egg-shell" china, very thin and translucent. But they made ordinary pottery too.

EUROPE

After the decline of the Roman Empire, the ceramic art more-or-less died in Europe. It did not come to life again for many centuries.

Eventually it came to life again due to the Arabs and Saracens in Spain. They used porous material with milky-white opaque glaze based on tin oxide. Decorated with blue enamel and had a "golden lustre". The best work came from Majorca and was largely exported, especially to Italy. This type of ware became known as Majolica (a corruption of Majorca).

The Italians copied the Spanish ware, but from around 1400 AD developed their own styles. A lot of emphasis went on ceramic statues and ornamental ware,

e.g., alter pieces.

An interesting point is the way in which the name of one pottery place got attached to a style in another country. We have already mentioned Majolica from Majorca. The French named a style "Faience" after the town of Faenza in Italy where the glazed porous pottery was largely made. The English named a fine glazed pottery style "Delft"-ware in 17th century after the town of Delft in Holland whence it originated.

France made glazed earthenware (faience) from the 12th century.

Soft porcelain originated in France in 1693 as a result of attempts to produce real (hard) porcelain. It was made from ground glass (called "frit") mixed with a little clay to make it plastic. Very difficult to work. Several factories established for it, notably at Vincennes near Paris, transferred by Louis XV to Sèvres.

In 1761, Sèvres factory obtained the secret of real porcelain from Germany. Germany had been making stoneware from the 12th century (as well as faience later). But in 1708 Böttcher succeeded in developing true porcelain. He had already improved stoneware greatly, but by discovering the location of some kaolin he was able to make white translucent porcelain. A great factory was established at Meissen near Dresden. The quality of decoration improved until it reached the famous Royal Dresden standard later in the 18th cent. Great secrecy was observed, but nevertheless the secret got to Vienna through two workmen who were bribed.

In Britain the earliest native ware found dates from the 13th cent - coarse earthenware jugs with green or yellow glaze. 16th cent. saw "Cistercian" ware - coarse faience, glazed black or dark brown.

But in the 17th cent, slip ware developed and reached a high state of perfection - especially in Staffordshire. Earthenware body was rather coarse but the decoration was done with orange, white and red slips. About the same time, some Dutch potters settled in Lambeth (c.1650) and eventually about 20 manufacturers were making the white-glazed Delft ware, decorated in blue &c. By the end of the 18th cent, however, the industry ceased as a result of the successful competition of the Staffs earthenware.

{ John Dwight made soft frit porcelain in 1670 (which anticipated the French) but he could not manufacture it successfully. }

The Staffordshire potters developed both stoneware (brown and later white) and earthenware to a high degree of perfection during the 18th cent. The Ehlers brothers, and later Astbury, were the chief producers of the former. The famous Josiah Wedgwood, with his own factory from 1757, was the chief producer of fine earthenware, using China clay to improve the white body, and using a mixture of flint glass, zinc oxide and sand for the glaze. "Queen's Ware" was an example of his work, so named because he produced a special set for Queen Charlotte in 1765. Mass production of decorated ware was improved in 1752 by Sadler & Green of Liverpool who used engraved copper plates to transfer prints to pottery. English earthenware was famous all over the world.

English hard porcelain started in 1760 when Cookworthy established his factory in Plymouth, using Cornish china clay. He developed the method of making hard porcelain in 1768. The method was too expensive (remember that German porcelain had been available since 1708) and he had to cease manufacture in 1774. Few other manufacturers were able to keep going for long. Hard porcelain was manufactured in Plymouth, Bristol, New Hall (Staffs.) Lowestoft and Liverpool during the half century around say 1760–1820.

England was more successful with soft porcelain around roughly the same period. Factories at Bow, Chelsea, Derby, Worcester (still in production!) became famous . Bone china was developed as an exclusively English production by Josiah Spode in 1805, using bone ash in place of the glassy ingredients of soft paste porcelain. Easier and cheaper to make then soft porcelain, yet more translucent and more suitable for brilliant underglaze decoration than hard porcelain.

Summary of History.

Secrecy (and lack of communication) meant that independent developments took place in different countries.

Bricks before 5000 BC

Terra cotta from around 3000 BC in Egypt and China and India

Primitive earthenware (glazed) ditto Egypt and China

High quality earthenware from around 1000 BC in Egypt and later in Greece and Rome

Porcelain from around 600 AD in China and from around 1700 AD in Europe

Stoneware from around 100 BC in China

References on Ceramics

1 E. Rosenthal, "Pottery and Ceramics", Pelican Books, 1949.