THE PROPERTIES OF CLAY

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Abstract

Clays are heavy, soft, sticky and pliable firm earth minerals, which have been derived by the process of weathering and hydrothermal degradation of igneous rocks. When baked at high temperature, the clay bodies become hard. Since the development of the first human settlement till today, societies have made distinctive forms of clay as a basic production material to create the technological awareness that boosted pottery craft. This paper provides some insights on the properties of clay to accelerate pottery production and continued improvement.

Introduction

Clay is a naturally occurring material composed primarily of fine-grained minerals, which show plasticity through a variable range of water content, and which could be hardened when dried or fired. Clay deposits are mostly composed of clay minerals (phyllosillicate minerals), which impart plasticity and hardened when fired and / or dried, and variable amounts of water trapped in the mineral structure by polar attraction. Organic materials which do not impart plasticity may also be part of clay deposits.

In Nigeria, nature has clay deposits, which have existed for centuries and many of the deposits are still undiscovered. Those that have been discovered are serving the neighbouring potters who have flair for preparing their own clay bodies.

Formation of Clay

Clay minerals are typically formed over long periods of time by the gradual chemical weathering of rocks, usually silicate-bearing, by low concentrations of carbonic acid and other diluted solvents. These solvents, usually acidic, migrate through the weathering rock after leaching through upper weathered layers. In addition to the weathering process, some clay minerals are formed by hydrothermal activity. Clay deposits may be formed in place as residual deposits, but thick deposits usually are formed as the result of a secondary sedimentary deposition process after they have been eroded and transported from their original location of formation.

Definition of Clay

Clays are distinguished from other fine-grained soils by differences in size and/or mineralogy. Silts, which are fine-grained soils which do not include clay minerals, tend to have larger particle sizes than clays, but there is some overlap in both particle size and other physical properties, and there are many naturally occurring deposits which include both silts and clays. The distinction between silt and clay varies by discipline. Geologists and soil scientists usually consider the separation to occur at a particle size of 2 micrometres (clays being finer than silts), sedimentologists often use 4-5 micrometres and colloid chemists use 1 micrometre. Geotechnical engineers distinguish between silts and clays based on the plasticity properties of the soil, as measured by the soils (Guggenheim, Stephen & Martin (1995).

Types of Clay

In Nigeria, there are two types of clay: primary or residual and secondary or sedimentary clays. Primary clays are made of weathered particles that remain close to their parent rock; they are not carried away by water, wind or glaciers. They have relatively large particles and are largely free from impurities.

Secondary clays are carried away from their source by eroding forces (Coiler, 1976). As the clay is transported, especially by running water, some large particles are left on the way while the remainder is carried further and is ground finer by the water on the eroding force. As a result, the particles of secondary clays are smaller than those of primary clays. On their journey, secondary clays become mixed with other substances such as Iron, Quartz, Mica and Organic residue. They therefore contain more impurities than the primary clays and are usually very plastic.

Chemistry of Clay

The potter accepts clay as a medium of many properties. The chemist sees clay as a complex mixture and combination of minerals. The chemist gives an analysis of clay in two ways. One way separates the oxides, lists them and possibly gives amounts. The other tries to give some idea of the clay's properties by grouping the oxides as clay content, feldspar, mica etc. for example, Frank (1975) analyzed clay as:

Clay content	-	50%
Feldspar	-	15%
Free silica	-	29%
Plus		
Iron Oxide	-	1%
Limestone	-	5%.

He reiterated that the clay content, which was based upon the clay crystal structure have the formula: $Al_2 O_3. 2SiO_2. 2H_2O$ and this gives it a composition of:

alumina	39.5%
silica	46.5%
water	14.0%

From the aforementioned, it would be noticed that there is 14% of water in the form of hydroxyl groups (OH) in the gibbsite layer and therefore, many chemists prefer to describe the clay crystal by the formula $Al_2 Si_2 O_3 (OH)_4$. They also call it hydrated aluminium silicate.

Clay contains water in the crystal structure called bound water; water in the holes between the particles called pore water; and water to allow the particles to slide past one another called water of plasticity.

In dry state, clay contains bound water. During firing, this water becomes steam, which escapes slowly over a period $450^{O}C$ to $600^{O}C$. The bound water would escape as steam without causing trouble because the pores of the clay are open at this temperature. It is very unlikely that any pot would burst from the escape of this water, which would be seen escaping from the kiln at the aforementioned temperature.

Dry clay also contains pore water. This remains in the pores and does not dry out because there is water in the atmosphere.

Plastic clay contains more water still. This is the water of plasticity. In extreme cases, this water of plasticity could account for 30% of the weight of plastic clay but 20 to 25% is more normal. Hence, plastic clay would have the formula: $Al_2 O_3 . 2SiO_2 . 2H_2O . 5H_2O$ and a percentage analysis of:

alumina	-	26
silica	-	30.5
bound water	-	9.25
pore water	-	9.25
plasticity water	-	25.

Seen thus, it is not surprising that there is shrinkage from plastic state to fired body.

Physics of Clay

The physics of clay is concerned with the size and shape of the clay crystal and resulting agglomerate particles; and the effects arising from these. The effects concern plasticity and shrinkage (Odubiyi, 2004).

The shape and form of the clay crystal are dependent upon its lattice structure. Each sheet of aluminium silicate structure contains thousands of atoms. Thousands of sheets layered on one another produce a clay crystal. The layers do not fit over one another in exact repetition, but are slightly displaced since there is no reason for exact location. However, the overall crystal has a roughly hexagonal appearance and is of course flattish.

These crystals must not be confused with clay dust or grains. These crystals are so small that they are invisible to the naked eye. Many hundreds of particles make up a grain of clay dust and because of the electrostatic forces of attraction and the compression that clays at rest have undergone; the larger grains are often replicas of the smaller crystals. That is, they are flattish and roughly hexagonal.

Water is the lubricant between the particles. If there is plenty of water, the particles could slide past one another without difficulty. In such a case, there is little friction. Very soft, wet, plastic clay is in this state. When there is less water between the particles, there is some thickness, like a wet pack of cards. In this case, the friction gives strength. Stiff plastic clay is in this state. As the water dries out of clay, the particles are brought closer together. The clay object becomes a solid.

The water gives plasticity because the particles are able to hold onto one another. The clay particles could hold onto one another by suction. The water between the particles gives the necessary seal.

Clay particles position themselves with their flat faces opposing the direction of pressure. An extreme example of this is seen in compressed clays, which have become shales. However, in all potting use, the particles are being asked to rearrange their relative positions. Rolling and press moulding lays the particles flat along the clay sheet. This gives strength. In kneading clay, the particles are placed concentrically. This gives a circular strength, which is useful on the wheel and is further added to by the centering process. During opening of the clay in throwing, the base of the pot is compressed. This lays the particles flat across the base giving strength. It also makes the larger drying shrinkage through the thickness of the base rather than across the base. The firing shrinkage also follows this course. A compressed base is less likely to crack than an uncompressed one. The uncompressed one often tears apart in what is called an S crack and lids which are thrown upside down often shrink more than the pots they were measured to fit.

Clay Minerals

Clay is the common name for a number of fine-grained, earthy materials that become plastic when wet. Chemically, clays are hydrous aluminium silicates, usually containing minor amounts of impurities such as potassium, sodium, calcium, magnesium, or iron.

One of the commonest processes of clay formation is the chemical decomposition of feldspar. Clay consists of sheets of interconnected silicates combined with a second sheet-like grouping of metallic atoms, oxygen and hydroxyl, forming a two-layer mineral such as kaolinite. Sometimes, the latter sheet like structure is found sandwiched between two silica sheets, forming a three-layer mineral such as vermiculite (Hillier, 2003). In the lithification process, compacted clay layers could be transformed into shale. Under the intense heat and pressure that may develop in the layers, the shale could be metamorphosed into slate.

Properties of clay minerals include plasticity, shrinkage, under firing and air drying, fineness of grain, colour after firing, hardness, cohesion, and capacity of the surface to take decoration. On the basis of such qualities, clays are variously divided into classes or groups.

Individual clay particles are always smaller than 0.004mm. Clays often form colloidal suspensions when immersed in water, but the clay particles flocculate (clump) and settle quickly in saline water. Clays are easily moulded into a form that they retain when dry, and they become hard and lose their plasticity when subjected to heat.

Clays are divided into two classes:

1. Residual clay – found in the place of origin.
2. Transported clay, also known as sedimentary clay, removed from the place of origin by an agent of erosion and deposited in a new and possibly distant position.

Residual clays are most commonly formed by surface weathering, which gives rise to clay in three ways:

1. Chemical decomposition of rocks, such as granite, containing silica and alumina.
2. Solutions of rocks, such as limestone, clayey impurities, which being insoluble, are deposited as clay.
3. Disintegration and solution of shale (Ehlers, Ernest and Harvey, 1982).

Clay rocks could be identified by their very fine grain size of < 0.002mm, and have different properties depending on which particular clay minerals they contain. There are three main groups of clay minerals, each with its own particular properties:

1. Kaolinite
2. Illite
3. Montmorillonite

Clay rocks may contain a mixture of these minerals, so they have very variable properties, giving rise to a number of different uses. The most abundant use of clay is in brick-making.

Granite is made up of quartz, mica, and feldspar. As quartz is resistant to chemical weathering, it may be removed only as mineral grains of quartz, feldspars and micas are susceptible to chemical weathering and break down to form clay minerals.

Some of the original elements contained in the micas and feldspars are carried away in solution as irons (Na^+, Ca^+, and K^+), and so the clays formed are relatively enriched in aluminium and silicon.

The main groups of clay minerals are kaolinite, illite and montmorillonite. The layers of kaolinite are held together by fairly weak bonds, whereas there is strong bonding in illite and montmorillonite because of the presence of positively charged metal ions; potassium in the case of illite, and calcium and sodium in the case of montmorillonite.

Generally, potassium feldspar breaks down to form kaolinite; micas weather to give illite and ferromagnesian minerals break down to form montmorillonite.

Uses of Clay

From pre historic times, clay has been indispensable in architecture, in industry, and in agriculture. As a building material, it is used in the form of brick, either sun dried or fired. Clays are also of great industrial importance, e.g. in the manufacture of tile for wall and floor coverings, of porcelain, china, and earthenware and of pipe for drainage and sewage.

Pottery craft depended on the exploitation of several intrinsic qualities of clay - its plasticity, its ability to hold the shape into which it is formed as it dries and the fact that heating it to maturity transforms it into a new, permanently hard substance.

The knowledge and technique necessary to transform damp clay into ceramic material developed at various times in different cultures, but no matter where the craft evolved, it influenced the development of that culture. Let us now look at few of these examples:

1. The knowledge of clay allowed the villagers to make vermin-proof storage jars, which meant they could store grain against future crop failure and accumulate surpluses with which to trade with neigbouring communities.
2. Clay tablets were used as the first writing medium, inscribed with cuneiform script through the use of a blunt reed called a stylus.
3. Prehistoric human discovered the useful properties of clay, and one of the earliest artifacts ever uncovered is a drinking vessel made of sun-dried clay.
4. Clays sintered in fire were the first form of ceramic – bricks, cooking pots, art objects dishware and even musical instruments such as Udu drum (in the eastern part of Nigeria) and Ocarina could all be shaped from clay before being fired.
5. An object made with clay is indestructible unless it has been crushed into minute fragments that could not be repaired. This has made it easier for archaeologists and historians to reconstruct how people lived in cultures that have long since disappeared. Even if a clay pot has been broken, its shards could often be put together again (Odubiyi, 2004).

Conclusion

In conclusion therefore, this paper has highlighted the properties of clay in many cultures and adequate knowledge of the formation of clay, definition of clay, types of clay, chemistry and physics of clay, the properties of clay minerals and the uses of clay would be an added advantage to those who would like to explore this medium of expression to address our numerous environmental needs through pottery production and continued improvement.

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