

An Analysis of the Production and Manufacture of the Modified Clay Pot
at the Oriang Women's Pottery Group, the Amilo-Rangwe Pottery Group,
and the Kinda E Teko Pottery Group in Nyanza Province, Kenya

by

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ABSTRACT

In response to the growing demands for safe water supplies and the absence of a central infrastructure capable of meeting those demands, CARE-Kenya has implemented a safe water storage program at the household level. Central to this program is the modified clay pot, a hybrid of traditional Kenyan pottery and safe water storage principles. The modified clay pot exhibits a flat base for stability, a narrow neck to prevent access and thus reducing the chances of contamination, a standardized size in order to be compatible with chlorine dosing standards, and a tap at the base to provide safe access to the water within.

The goal of this thesis is to analyze and record the production and manufacturing methods used by three local pottery groups in rural eastern Kenya using a combination of video, photography and written text. The primary focus of this work is to examine the ways in which the production processes could be improved and refined in order to increase both the efficiency of production, thus reducing the cost, and increase the scale of production, in order to increase availability of the modified clay pot to people within the Nyanza Province of Kenya.

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Chapter 1

Introduction

One of the main components necessary for providing access to safe water is the ability to safely store it. Whether the water is obtained from an improved source, such as a protected well, treated by way of a particle removal process, such as by using filters or a coagulant, or disinfected through SODIS, household chlorination, or some other method, the potential for contamination undermines and negates the resources spent ensuring the water is safe to drink at the point of consumption. Contamination can occur through a variety of routes, including but not limited to using dirty containers for transport, introducing pathogens by dipping dirty hands or cups into the water, or leaving the container uncovered. One approach to addressing these issues is the use of a designated safe water storage container. Safe Water Storage containers are designed to eliminate potential routes of contamination when used properly, by providing a fully enclosed container with a spigot that enables safe access to water.

In Kenya's Nyanza province, the NGO CARE Kenya is implementing their Safe Water Storage program using a modified version of a traditional wide mouthed clay vessel (Figure 1-1). The modified versions of the traditional wide mouthed clay pot, referred to as the modified clay pot, minimizes routes of contamination by having a narrow neck that prevents dipping containers into the water, and a spigot attached to the base that provides a safe mechanism for accessing the water (Figure 1-2). Additionally the natural porosity of the clay vessel provides an evaporative cooling effect, which makes the water more palatable than water from plastic containers that trap heat.

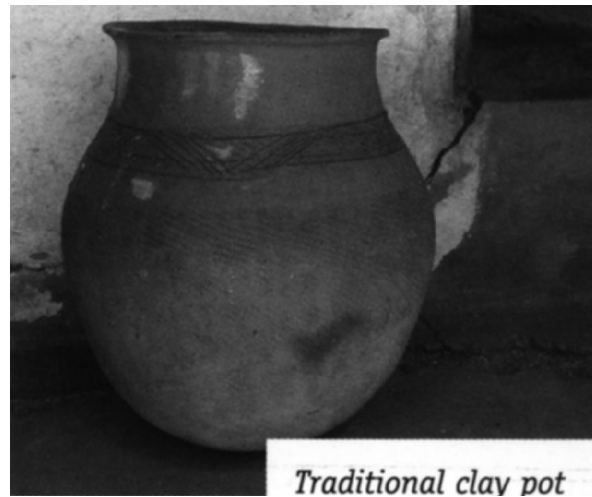


Figure 1-1: Traditional wide mouth clay pot [4].



Figure 1-2: Modified clay pot with flat base, tap and narrow neck.

Two groups under the auspices of CARE Kenya, the Oriang Women's Pottery Group and the Amilo-Rangwe Pottery group, and a third independent group, Kinda E

Teko, produce and locally distribute modified clay pots. Dissemination of the modified clay pot has been hindered by the price and inconsistent quality of the product. In order to reduce the price and improve quality the manufacture and production techniques used by the three groups were analyzed.

The production and manufacture of the modified clay pot is a multifaceted process that involves the gathering and processing of raw materials and commercial goods into intermediate components which are then assembled into the final product. The production and manufacture process can be characterized by the skills and materials required at each stage. It is important to understand how the choices in materials and the methods used at any given stage of production influence the final product. The production process can be divided into ten stages:

1. Gathering
2. Processing
3. Shaping
4. Modifications
5. Drying
6. Tapping
7. Firing
8. Sealing
9. Tap preparation and attachment
10. Quality assurance

Chapter 2

Gathering Clay

2.1 Clay as a Material Input

Clay represents the most significant component of the modified clay pot both in terms of the necessary material inputs and the effect the properties of the clay have on the finished pot. Material properties of the clay such as particle size, particle shape, mineral content, and organic content determine the suitability of the clay for molding, the strength of the clay before and after firing, and the leakiness of the sintered material [6]. Despite its overall importance to the manufacturing process, the pottery groups are limited to utilizing clays that are locally available. A combination of factors including limited scientific understanding of the local geology, the price of transportation, intensive required for processing, and the inherent variability present in clays impedes the proper development of clay into a reliable resource.

2.2 Geology of Clays

The three pottery groups are located in regions that are geologically favorable to the formation of clays. A geological map with the approximate locations of the three groups is presented in Figure 2-1. Clays can be classified into primary and secondary clays based on the mechanism of formation. Because of their material properties, only secondary clays can be used for the production of the modified clay pot [3].

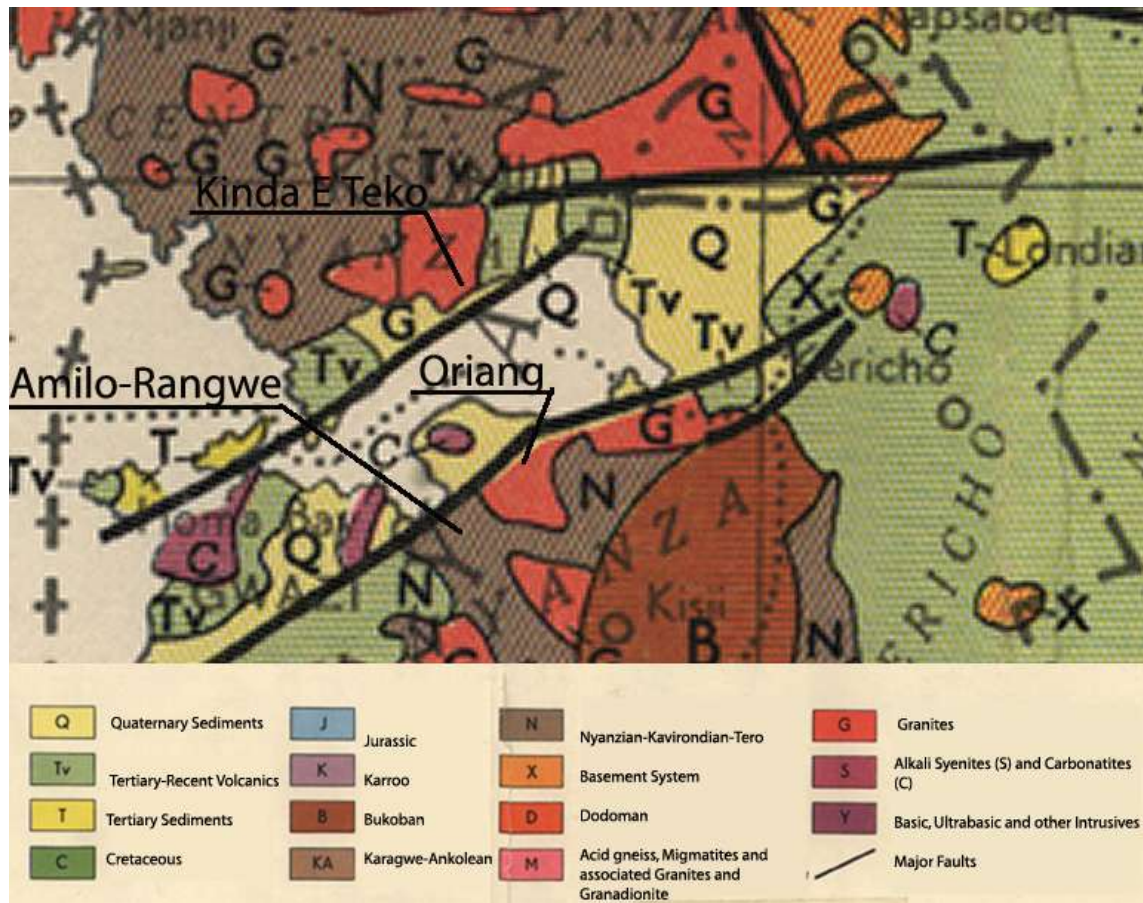


Figure 2-1: Modified, Geologic map of the Nyanza Province, Kenya. Locations of Oriang, Amilo-Rangwe, and Kinda E Teko groups marked. Scale 1:4,000,000 [2]

2.2.1 Clay Formation

The genesis of clay begins with the decomposition of silica containing igneous or metamorphic rocks. Depending on the conditions of decomposition a primary or secondary clay can be formed. Primary clays are formed at the location of the parent material by a series of chemical reactions with water, fluorine and boron. Secondary clays are sediments that have formed through weathering and erosion and are deposited at a new location. Primary clays tend to be relatively pure, and are used in the production of porcelain and other high temperature potter wares. Secondary clays tend to be coarser and contain impurities as a result of erosion and weathering. Impurities help impart color and plasticity to the clays, which make them well suited to the production of low temperature fired bodies like the modified clay pot [3].

One consequence of relying upon secondary clays is the inherent variability in the sources available. During transport the clays are exposed to a number of impurities before being deposited. The geologic processes of erosion and transportation act to separate the particles by size, creating deposits that exhibit progressive variation in size, color and composition of the clay. The natural levigation of clay combined with the introduction of materials, make clay deposits spatially heterogeneous and limit the potter's ability to obtain consistent source material for their wares. Clay deposits also tend to be very shallow because of the time scales over which erosion and transport take place, further limiting the quantities available to the potter [3, 9].

2.3 Locating and Accessing Clay

The ability to locate and identify deposits of clay is a limiting factor for the expansion of the SWS intervention program in terms of increasing production of the modified clay pot through the addition of new pottery groups. In attempts to expand production of the modified clay pot to other districts, CARE-Kenya has attempted to form new pottery groups trained in the production of modified clay pots. The inability to locate and identify new sources of clay has prevented expansion.

2.3.1 Gathering Clay

The process of gathering clay is a simple one. Using agricultural implements such as hoes or even bare hands, clay is mined from the surface or exposed faces of the earth. Due to the proximity of each group's clay sources, and a lack of proper storage infrastructure, clay is only mined in quantities large enough to keep the group supplied in the short term. The amount of clay mined at a given time depends on the structure and activities of the groups. The Oriang Women's Pottery group and the Kinda E Teko group are centrally organized, and a communal resource is kept at their workshops. Because of their larger membership and higher peak volume production of pottery ware, approximately 10 modified pots per day, the Oriang group maintains a larger stockpile at the workshop. The Kinda E Teko group, because of their smaller membership and lower peak production rates, approximately 4 modified clay pots per week, only maintain a small stockpile of clay. In contrast to the other groups, the Amilo-Rangwe group is organized into networks. Individual potters working from their homes maintain their own stockpiles of clay.

2.3.2 Effects of Weathering on Mining

The mining of clay is heavily influenced by seasonal variations in rainfall and the material properties of the clay. Kenya experiences two rainy seasons. The first rainy season extends from March through May. The second extends from October through December [1].

Rain influences the mining of clay in two ways. During the rainy seasons, wetter weather slows down production by increasing the drying times for the pottery. Additionally too much rain makes the earth unsuitable for mining and too little rain may make the earth too difficult to mine. Of the three groups, only Kinda E Teko indicated that they stockpiled clay prior to the rainy seasons. Clay material properties such as the particle size, which affects the drying rate, may also limit availability of certain types of clay. In interviews with potters from the Oriang Women's Pottery Group, one potter described that during periods of dry weather it was sometimes too difficult to mine finer clays due to the hardness of the material.

2.3.3 Securing Access to Clay

One of the major logistical aspects of mining and procuring clay is securing access to the physical resource. Access to clay can be gained by a variety of means ranging from the direct purchase of clay to renting the mining rights to a parcel of land. The arrangements each of the three groups have made span these options. The Oriang Women's Pottery group, the most financially independent of the three, actually owns the land from which it mines its clay. Using resources provided from a UNIDO grant, the Oriang group was able to purchase their own land. The Amilo-Rangwe group secures access by effectively renting a plot of land, and then mining it for clay. They pay approximately 2000 Ksh for the right to mine each plot of land until they are finished. On average each plot of land provides roughly enough clay to produce 50 40L modified clay pots. The Kinda E Teko Group mines their clay from the hills. But unlike Amilo-Rangwe, they do not pay for access to the land. Instead they pay for transport of clay via a donkey from the hill site to their workshop. Approximately one trip costs 25 Ksh and provides enough material to make 4, 40L modified clay pots.

2.3.4 Social and Economic Factors in Accessing Clay

Access to clay can vary due to a number of social and commercial factors. Because Nyanza is primarily a rural province and there is limited demand for commercially available clay and there are no distribution networks for the commercial sale of large quantities of clay. Additionally, there exist social taboos surrounding the sale of material from the earth. In interviews with potters of the Kinda E Teko group, they related that the clay they used used to be sold. However, the owners of the hill, eventually died of disease, brought on by the selling of the earth. After they died, it was decided that only transport would have to be purchased and that the clay would be free. While economically there may be little difference between the selling of clay, and the selling of transportation for the clay, such taboos prevent improved efficiency in the production process through the organization of groups who could mine clay and then sell it to the pottery groups.

Chapter 3

Processing Clay

3.1 Clay Properties

Clay in its raw state can be extremely heterogeneous, containing impurities and exhibiting a broad range of physical and chemical properties. The material properties of clay directly influence the mechanical, electrical and optical properties of the unfired and fired ceramic. The mechanical properties include the green strength (physical strength prior to firing), the plasticity of the clay, the strength of the ceramic after firing, and the porosity of the material. Electrical properties range from the resistance of the material to semi-conductor properties. Optical properties can range from the color of the ceramic to physical transparency of the material. A wide variety of chemical additives and processing is required to manipulate and control the precise physical properties of the final product [7].

3.2 Modern and Traditional Ceramics

Ceramics production can be divided into two general categories: Traditional and Modern. Traditional ceramics consists of pottery made from clays, and includes ceramics produced by ancient civilizations and traditional societies. Modern ceramics consists of objects made from any non-metallic inorganic materials. Modern ceramics is relative a new field, only recently developing in the early 20th century [6, 7].

3.3 Material Properties

The material properties manipulated during the production of modern and traditional ceramics reflect the range of applications of their products. Modern ceramics

are used in a broad range of applications from structural materials, to semi-conductors, to super magnets, and as a result a broad range of physical properties need to be specified during production. In contrast, traditional ceramics are used largely as containers, cooking ware, and art. The functionalities that can be achieved by the clay are limited to what shapes the clay can be form into, and the mechanical properties of the clay [7,8].

3.3.1. Impurities

The mechanical properties of clay are determined by the purity, the particle size distribution and reactivity of the material. Impurities can affect the material properties of the ceramic on a microscopic and macroscopic scale. On a microscopic scale chemical properties such as the viscosity of melts during sintering and chemical reactions between components are affected. On a macroscopic scale, impurities present in the form of inclusions create flaws in the material. Inclusions create regions where properties such as material elasticity or coefficient of thermal expansion (CTE) differ from the surrounding material. If the inclusion is less elastic than the surrounding material, it will serve as a focal point for stresses applied to the ceramic material. However, if the inclusion is more elastic and therefore softer than the surrounding material, it will not concentrate stress and only serve as a point of weakness in the material. For thermal expansion during sintering, an inclusion that has a low CTE will become fixed in the melted material. As the inclusion begins to cool it will not contract with the surrounding material, and create radial cracks in the material. However, if the material has a higher CTE, it will generate void spaces after expansion and contraction during sintering and cooling. Such a defect only has a minor effect on the overall strength of the material. The importance of the defect is also dependent on the size of the inclusion, the larger the inclusion the more severe the effect will be [7].

3.3.2 Particle Size Distribution

The particle size distribution and reactivity of the material influences the packing of particles during sintering. Particle packing affects properties such as strength and porosity of the ceramic. A ceramic sintered from clay consisting of a single particle size will not pack efficiently and result in a product with 30% porosity and low material

strength. If a range of particle sizes is used, the porosity can be reduced and the material strength increased. The reactivity of the material is another property that drives packing. Entropic effects due to exposed surface area drive very fine particles, diameters of 1 μm or less, to reduce their surface collective surface area through chemical bonding. Under the proper conditions packing can effectively remove all the pore space and allow the material to approach its theoretical density [7].

3.4 Processing Techniques

A large number of techniques and processes have evolved in response to the growing sophistication of modern ceramics. Precision level control is required over the properties of the material inputs in order to specify the properties of the final product. However, in traditional ceramics clays can occasionally be used in their raw natural state or processed to varying degrees to achieve certain mechanical properties. Most clays will need to be processed to some extent before being used in production due to the presence of heterogeneities and impurities in the raw material. The mechanical properties of the clay can be adjusted primarily through the addition and removal of material. Four basic techniques are used for processing clay in traditional ceramics: aging, screening, conditioning, and tempering [6].

3.4.1 Aging

Aging is a process that utilizes time dependent mechanisms to modify clay properties. The simplest aging technique involves allowing the clay time to set so water can fully permeate the mass of the material. Over the span of few days aging is thought to increase workability by allowing water to fully permeate the body of the clay, introducing a microfilm over all the particles. Over longer periods of time, it is thought that bacterial processes may contribute to aging and the modification of the clay [6].

3.4.2 Screening

Screening is the removal of inclusions and impurities through physical exclusion based on particle size and the size of the openings in the screen. Screening can be performed on either dry or wet clay. To prepare clay for dry screening, the clay has to be dried, crushed and ground to a fine powder. Wet sieving requires the addition of water until the material is suspended in a slurry. Screens are simple devices and can be constructed from screen meshes, baskets, perforated metal sheets, cloth, or even rawhide punched with holes. Screening is capable of filtering dry material up to 325 mesh and wet material up to 500 mesh. A second process, similar to screening, for removing impurities is known as levigation. Unlike screening, levigation operates by sorting particles of different sizes due to differential settling rates in water. Larger particles settle faster and can be separated out from the rest of the material. In terms of production, screening is critical for removing inclusions from the clay that may introduce flaws, create cracks or destroy pottery during firing [6, 7].

3.4.3 Conditioning

Conditioning involves systematic manipulation of the clay material to ensure homogeneity. Conditioning consists of manipulation of clay through kneading, wedging or foot treading. Kneading simply involves hand mixing the clay. Wedging is a slightly more sophisticated process where clay is sliced using a thin wire, and then recombined and mixed together. Foot treading, a technique well suited for processing large amounts of clay involves spreading the clay into a thin layer over the floor and walking over it. Conditioning eliminates air pockets that result in large voids or ruptures during firing. Conditioning improves workability of the clay by ensuring that the material is uniform in terms of water content and impurities [6].

3.4.4 Tempering

Tempering is the addition of material to the clay. Tempers range from quartz sand to ground up pottery shards to cow dung to saw dust to wheat flour. Tempers are introduced into clays to improve plasticity, to increase the green and fired strength, to

increase porosity and to increase the workability of the material by reducing the stickiness. Tempers are important because they allow a variety of clays to be used through modification of their composition. The preparation of temper is dependent on the material being used. In general tempers are crushed and then sieved to obtain a fine uniform mixture before adding it to the clay [6].

3.5 Pottery Groups: Processing

Each of the groups employs a different set of techniques based on the material properties of the clay they use.

3.5.1 Oriang

3.5.1.1 Aging

The Oriang Women's pottery group allows their clay to sit for at least one night soaked with water. Of the three groups they were the only one who visibly took advantage of the long-term effects of aging by keeping stockpiles of clay and allowing them to sit for extended periods of time. The clay is covered with plastic weighted down by bricks to prevent drying out and contamination (Figure 3-1).



Figure 3-1: Aging clay at Oriang. The clay is covered with plastic tarp and bricks to prevent drying out.

3.5.1.2 Screening

No screening techniques are used in the processing of the clay by the Oriang group.

3.5.1.3 Conditioning

The clay is manually manipulated and folded over to increase homogeneity in the mixture. Small amounts of water are periodically added and large inclusions are manually removed (Figure 3-2).



Figure 3-2: Oriang potters manually kneading clay.

3.5.1.4 Tempering

The clay is tempered with sand (Figure 3-3). Sand is added until the clay no longer sticks to the hand. Depending on where the potters live, they either gather fine sand from a river or coarse sand from the fields. Both sands are sieved using a visibly warped 200 mesh sieve (Figure 3-4) to remove large impurities. Warping in the sieve will enlarge openings allowing larger material through, increasing the chance of defects. Observations from the potters have indicated that pottery made from the finer sand results has a reduced porosity. Qualitative observations about porosity are based up on the rate at which the pottery leaks water through its surface. The clay is then further conditioned by hand kneading, while large inclusions are removed.



Figure 3-3: Oriang potters tempering clay with sand.

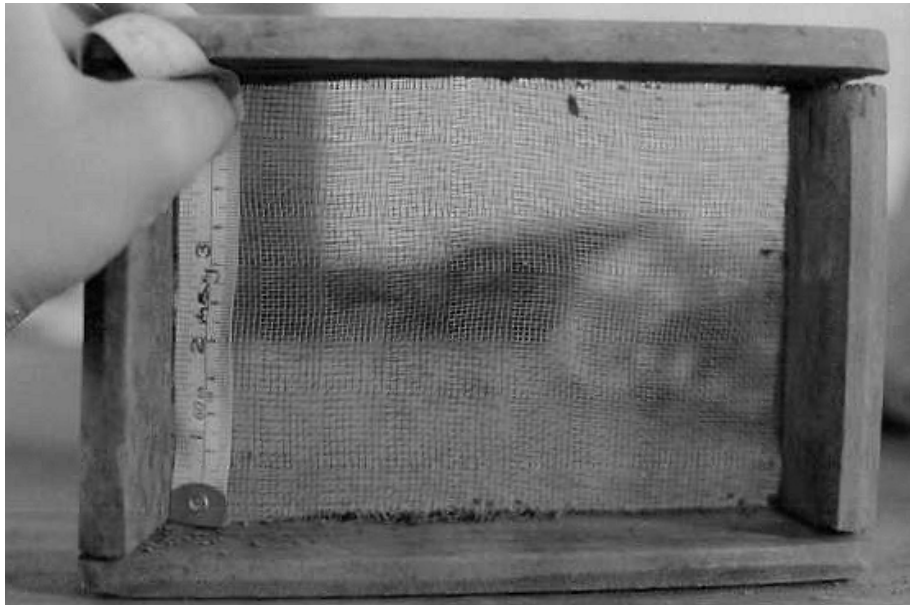


Figure 3-4: Closeup of Oriang sieve. Used for preparing sand for tempering. Mesh size approx 200.

3.5.2 Amilo-Rangwe: Processing

Observing the processing of clay at Amilo-Rangwe was complicated because the potters would prepare the clay at home before bringing it to workshop.

3.5.2.1 Aging

The clay is stored for various amounts of time depending on the rate of use, but there are no explicit steps for aging used by the Amilo-Rangwe group.

3.5.2.2 Screening

No screening techniques are used by the Amilo-Rangwe Group.

3.5.2.3 Conditioning

The clay is manually kneaded and folded over, while large inclusions are removed by hand.

3.5.2.4 Tempering

Sieved sand is added to the clay until the clay no longer sticks to the hand

3.5.3 Kinda E Teko: Processing

3.5.3.1 Aging

The Kind E Teko pottery group begins processing their clay by letting it dry for an entire day (Figure 3-5). The clay is then mixed with turbid pond water on stone tablet, and then stored in a clay vessel (Figure 3-6). The clay then sits for a day until it reaches the proper consistency.

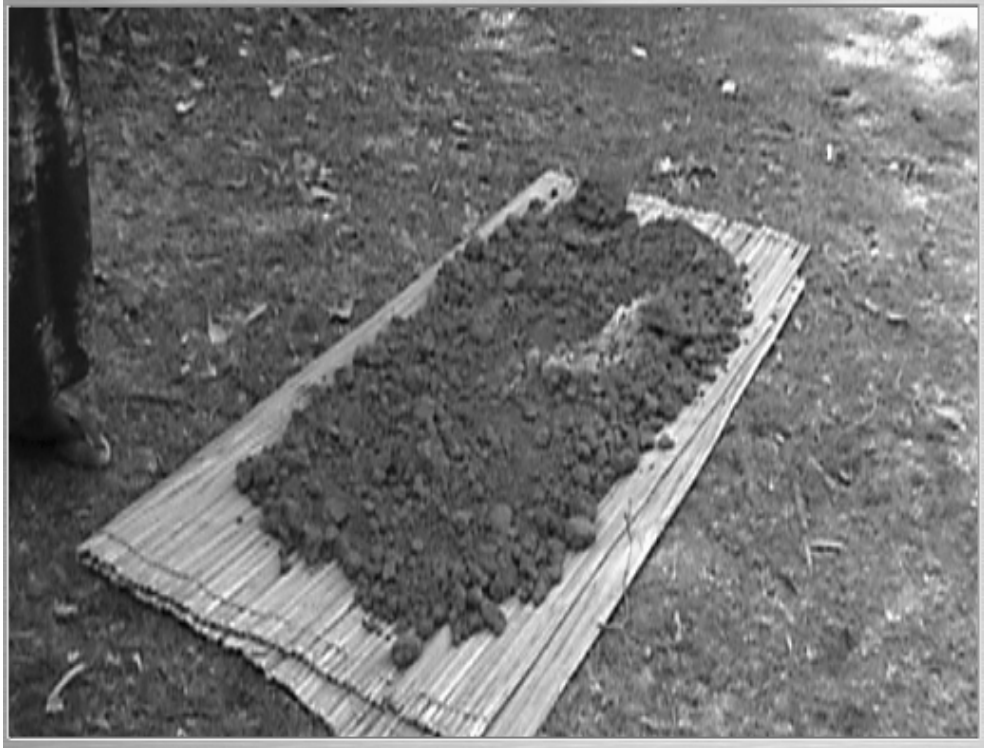


Figure 3-5:Clay drying at Kinda E Teko.



Figure 3-6: Kinda E Teko potter preparing clay. Clay is mixed with pond water on a stone tablet and then stored in the vessels in the back.

3.5.3.2 Screening

No screening techniques are used by the Kinda E Teko group.

3.5.3.3 Conditioning

The clay is kneaded and mixed with water until it reaches the proper consistency. Inclusions are also manually removed (Figure 3-6).

3.5.3.4 Tempering

No tempers are used to process the clay by the Kinda E Teko group. It is suspected the clay has a naturally low plasticity, which alleviates the need for tempering. Additionally, the clay exhibits a low level of surface leakage, implying a naturally low porosity.

Chapter 4

Shaping

4.1 Differences between Shaping for Modern and Traditional Ceramics

The shaping and formation of ceramics is one of the most technically demanding steps in production. From the perspective of modern ceramics, the physical molding and shaping of material is a complicated process where the chemical and physical properties of the source materials can generate flaws and heterogeneities in the finished product. For example, in precision designed components tolerances will be ruined if there is improper packing of material that leads to variations in density and material thickness. Even simply sticking to the mold will ruin a cast object. In traditional ceramics no aspect of production is precision based, allowing minor flaws and variations to have no appreciable effect on the overall functionality of the object. If a pot is formed asymmetrically, while it may potentially be aesthetically unpleasing, it will be just as functional as a symmetric one. The difficulty comes from the skill needed to manipulate the clay into a form that is not only functional but that is also capable of surviving drying and firing. For example thick layers may provide more structural support while the clay is drying, but they can lead to cracking because of differential drying rates between the exterior and interior. The techniques utilized in the formation of modern and traditional ceramics highlight aspects of production that are critical to each [6,7].

4.2 Forming and Shaping in Modern Ceramics

There are three main groups of techniques used in the forming and shaping of modern ceramics: Pressing, Casting, and Plastic Forming. Each of these techniques has advantages and drawbacks that make them well suited for particular tasks.

4.2.1 Pressing

Pressing is the simplest of the shaping methods, using pressure to compact a dry powdered material into a die (This process should not be confused with using a press to mold wet clay, which falls under the category of plastic forming). Pressing can be divided into two categories: uniaxial and isostatic. Uniaxial pressing involves the application of force from a single direction to force the material into the die. Because the process is very simple, it is easy to automate and can regularly achieve high production rates. The simplicity of the process also reduces the amount of control available over forming the material. Non-uniform densities can occur because pressure gradients created by friction between the material and the walls of the die. Material in high-pressure regions will compact, generating higher densities, while material in low-pressure regions will only partially compact, achieving lower densities. Variations in density result in defects during sintering. Isostatic pressing is a more sophisticated method of pressing where uniform pressure is applied over the entire body of the material. Isostatic pressing is capable of generating more uniform densities and forming more complicated shapes. However, isostatic pressing is not capable of reaching the production rates of uniaxial pressing due to longer compression times and more complicated equipment [7].

4.2.2 Casting

Casting is a process where the source material is suspended in water and then poured into a mold. Material gradually accretes and dries as water is absorbed through the mold. Additional material is added until the desired thickness is reached. Unlike pressing where the entire shape of the material is constrained by the die and press, casting relies upon a host of parameters such as pH, viscosity, temperature and time. Casting processes can generate thick and solid items, and can produce sinks and crucibles. One of the advantages of casting is the capability of producing high density materials that exhibit little shrinkage during sintering. However, casting is limited as a production technique by long production times due to drying [7].

4.2.3 Plastic Forming

Plastic forming is the shaping of material through the application of pressure. In contrast to pressing where the source material is powdered, the material in plastic forming is, as the name suggests, plastic. In fact most production methods in traditional ceramics fall under the heading of “Plastic Forming.” In clay materials, water is added to produce plasticity. Chemical additives in the form of flocculants, wetting agents, and lubricants are added to make the material more workable. For non-clay materials a combination of organics and water are added to provide plasticity. Once the material is prepared it can be extruded or injection-molded. Extrusion generates long lengths of material with constant cross section such as piping, tubing, and heat exchangers. Extrusion operates by forcing plastic material through a die to impart shape. Extruders can range from simple setups consisting of a piston and barrel attached to a die to an all in one device that mixes and conditions the material prior to extrusion. Though a relatively simple process, extrusions are subject to a number of defects, such as distortion and tearing. Distortion can result from variations in density or misalignment of the mold or the design of the die. Variations in density can occur if the material is not uniform. Misalignment of the mold causes uneven extrusion of material across the mold, causing bending as more material exits from a particular side. Tearing is caused by friction between the material and the die as it exits the mold and results in cracks in the surface of the material [7].

4.2.3.1 Injection Molding

Injection molding is a process where ceramic powder is mixed with plasticizers and polymers, heated, and then injected into a mold. As a production tool injection molding is capable of high production rates for complex structures, however the capital investments in dies can cost thousands of dollars, and eventually wear out. Defects in injection molding generally occur because of void space in the die or premature cooling of the injectant. Air bubbles in the injectant will create voids that lead to cracking and malformation. Similarly, premature cooling will effectively remove parts of the mold by

blocking the paths of the flow. Molds for injection molding have to be carefully designed in order to ensure that material is capable of filling the entire mold before cooling [7].

4.3 Forming and Shaping in Traditional Ceramics

Traditional ceramic production methods are a low-technology subset of the Plastic Forming techniques used in the production of modern ceramics. While many of the processes in modern ceramics are automated and regulated at the molecular level they are in many ways analogous to the ones used in traditional ceramics. Unlike modern ceramic shaping processes, traditional ceramics are sub-categorized based on specific details of how the clay is formed rather than only the form of clay being used. There are six basic procedures for forming traditional ceramics: pinching/drawing, slab modeling, molding, coiling, throwing, and casting. The procedures are listed in increasing technical difficulty. The first five procedures are forms of plastic forming, and the last one encompasses casting techniques. Each procedure has its own limitations and benefits in terms of the objects it is capable of producing. Often a single shaping technique can be used to produce a single item, but multiple techniques can easily be combined to produce objects in a piecewise fashion. In addition to the shaping techniques there are ancillary tools and methods that influence the shaping process. These ancillary methods represent various levels of technology that are in use and available to the potters [6].

4.3.1 Drawing and Pinching

The simplest of forming techniques, drawing and pinching is manual manipulation of the clay body. A single lump of clay is used, and the fingers are inserted to create an opening. The clay is then thinned using the fingers to pinch it until it has become the desired thickness. This technique requires no additional tools, and can be performed on pieces of clay small enough that they can simply be hand held while being worked. Drawing is a slight variant of pinching, and is used to create larger and taller vessels. Once the lump of clay has been opened up, the material is then drawn and extended upward [6].

4.3.2. Slab Building

Slab building is a piecewise approach to forming pottery. Instead of molding an object from a single lump of clay multiple slabs of clay are formed and then joined together. Slab building is well suited for producing large rectangular vessels. A single slab can even be rolled to form a cylinder. A variant on this method involves a patchwork approach whereby numerous patches of clay are flattened and then successively joined to form the vessel body [6].

4.3.3 Molding

Molding is a technique where the vessel's shape is determined by fitting clay to a mold. A vessel can be formed from a single mold, formed from multiple molds, or formed from a combination of molding and another technique. Vessels made from a single mold tend to be bowl shaped, allowing for easy detachment of the clay from the mold. Multiple molds can be employed to create components of vessels with more complex shapes, such as the two halves of a closed vessel. When used in conjunction with other shaping methods molding is often used to start the base of the object [6].

4.3.3.1 Mold

The physical mold can take a variety of forms. More refined molds can be fabricated from plaster or fired clays. However, molds can also be formed in an ad hoc manner using broken vessel fragments, containers, or depressions in the ground. The mold itself can be convex or concave. Clay is applied to the outside of convex molds and allowed to dry. Due to contraction of clay during drying, the clay must be removed from the mold before it has begun to crack from the build up of stress, but after it has dried enough to retain its shape. For a concave mold, clay is applied to the inside of the mold. Because the clay shrinks away from the mold rather than onto it, there are fewer complications in removing the material before it has dried properly. Additionally because concave molds form the exterior surface of the object, relief patterning or decoration can be incorporated by decorating the surface of the mold. One problem common to both concave and convex molds is separation of the clay and the mold without sticking.

Parting agents that reduce the stickiness of the clay can be used at the clay mold interface to prevent sticking. Parting agents are tempers, such as ash, manure, pumice or fine sand, normally incorporated into the body of the clay, but instead are applied to the surface [6].

4.3.4 Coiling

Coiling is a shaping process suited for producing large storage vessels. It consists of building up long ropes of clay in succession to form the outer wall of the vessel. Coiling consists of three variants: ring building, segmental coiling, and spiral coiling. Each variant differs in the mechanism for how the coils are joined and added to the vessel as it grows [6].

4.3.4.1 Ring Building

Ring building consists of stacking individual coils on top of one another and can be used to produce an entire vessel and then finished with another technique [6].

4.3.4.2 Segmental Coiling

Segmental coiling consists of building each layer from several small ropes, as opposed to a single one. Segmental coiling can either be used as a stand-alone method or combined with another to produce a vessel [6].

4.3.4.3 Spiral Coiling

Spiral coiling is a technique where the entire body of the vessel is treated as a single coil. Instead of building and treating each layer separately, rolls are added in succession effectively creating the body from one continuous spiral. In practice spiraling is done using several segments, but it can be done using a single coil. Spiraling is generally used as a stand-alone method [6].

4.3.4.4 Coil Formation

The individual coils are formed by hand squeezing and rolling the clay into long ropes. The diameters of the coils generally need to be 2 to 3 times desired thickness of the vessel to provide enough material to extend the vessel upward while merging with the previous layer. The coils are joined to the vessel by pinching, which affords a larger binding area than simply stacking them and creates a stronger bond. The junctures and seams that are created between successive coils can be removed by smoothing the surface. Defects in coiled property arise from the incomplete joins between successive coils due to drying [6].

4.3.5 Throwing

Throwing varies considerable from the other shaping techniques due to the consistency of the clay and the use of a potter's wheel. Throwing consists of working a body of clay on a spinning wheel, while taking advantage of centripetal force to shape the clay. The potter's wheel can take many forms, but generally consists of two wheels: the first wheel spins and serves as a workspace, the second wheel stores momentum and transfers it to the first. In order to work the clay while it is spinning, it requires that the clay be pliable and very plastic. Because of this, thrown clays tend to be finer, and are mixed with more water to attain the proper consistency. One of the difficulties with throwing clay involves centering the starting material, otherwise the pottery will turn out asymmetric [6].

4.3.6 Casting

Casting is a variant of molding, in which a fine clay is suspended in water and then poured into a mold. The mold then absorbs some of the water from the clay water mixture causing the clay to solidify around the mold. The excess clay and water is then drained off leaving the dried clay behind. Defects in casting can occur due to difficulties in controlling the desired thickness of the cast object [6].

4.3.7 Tools for Traditional Shaping Processes

The tools available to the potter during shaping have considerable influence on the efficiency of the process as well as the quality of the final product. The tools range from simple bases on which the clay is formed, to complex potters wheels that allow high speeds necessary for throwing to be achieved. Bases are needed to support the clay object as it is built up. Small objects made through pinching that can be supported in the hand do require any support. Larger objects need a base to support their weight and or accommodate their shape. A simple board, mat, clay disk or even the floor can be used to support objects that have a flat base. For objects with a rounded base, cradles, molds, or material can be built up around the base to provide support [6].

Once the object is supported, how the potter interacts with the object needs to be addressed. There are two fundamental ways the potter can approach the pottery: orbital and stationary. In the orbital approach, the potter treats the pottery as being stationary and simply works around the object building it up. Though this technique is highly inefficient, it is not uncommon. In the stationary approach, the object is placed on a device that is capable of turning either about its base or on a pivot [6].

A number of devices can accommodate the stationary approach, ranging from simple bases without proper pivots, to pivoted disks or turntables, to technically advanced potters wheels. Each of these devices contribute to the shaping process by providing rotation. There are three basic mechanisms by which rotation assists in the shaping process: rotary motion, pivoting, and centripetal force. Rotary motion provides access to all sides of the pottery, increasing the efficiency of production. A true pivot allows for precise centering, which is critical for maintaining symmetry in thrown pottery. Centripetal force generated through spinning assists in the shaping of material [6].

4.4 Techniques used by Oriang, Amilo-Rangwe, and Kinda E Teko Pottery Groups

4.4.1 Tools

The three groups rely on a number of common indigenous technologies to produce their wares. A list of tools is provided below:

Foot: measuring tape.

Kuga: A small cylinder with a textured surface, used for generating textured surfaces on the pottery in the form of cross-hatching (Figure 4-1).



Figure 4-1: *Kuga* made from plastic strapping. Used by Kinda E Teko potters.

Ombasa: The pliable outer covering of a nut from a local plant (Figure 4-2).

Approximately the size of a potato chip.



Figure 4-2: *Ombassa*: tool used for smoothing clay surface.

Tournette: Referred to by the groups as a “wheel” (Figure 4-3). A tournette is not a true potters wheel in the sense that it is capable of generating and sustaining high velocities due to the lack of a fly wheel. The tournette is locally made from a tire rim that has been arc welded to a bearing and mounted on a metal tripod. The tripod is also constructed out of metal stock that has been welded together.



Figure 4-3: Two potter's wheels. Constructed from hubcaps mounted on a bearing welded to a metal tripod.

4.4.2 Oriang

The potters at Oriang use segmented coiling combined with a stationary technique to form the modified clay pot. A plywood square, roughly a foot square and $\frac{3}{4}$ " thick, is

used to support the base of the pot. A piece of plastic wrap from product packaging is placed on the square prior to molding to prevent sticking to the board, and subsequent cracking due to stress generated between the surface of the clay stuck to the board and inner clay body. The board is then set on a small wheel called a tournette. At the time of our visit, the potters at Oriang had at least 10 functioning tournettes.

The potter begins molding by taking a fistful of clay and pounding it flat with the palm of her hand (Figure 4-4). Once the clay has spread out to a certain size the potter then pinches the edges, forming the beginning of the vessel wall. The base circumference of fired pots at Oriang ranged from 53.5 cm to 86 cm. Oriang primarily focuses on the creation of 40L modified clay pots, and during the time our visit there were no 20L clay pots available to measure. Once the base has been formed, the potter begins to form coils of clay by squeezing the clay into a cylinder shape, and then rolling it to smooth the edges. The coil is applied to the exposed edge of the vessel, and then pressed on, forming a join. The material is then pinched and extended upward, and the process is repeated extending the body (Figure 4-5).



Figure 4-4: Oriang potter forms base of vessel on wheel.



Figure 4-5: Midway through shaping stage.

Once the vessel is halfway finished, the potter wets and smooths the surface using an ombasa. Texture is then added using a *kuga* (Figure 5-5). The *kuga* used at Oriang is made of metal, and is placed flat against the exterior surface of the vessel wall and rolled with the hand, while the other hand supports the interior. In interviews with the potters they report that it is necessary to texture the surface before finishing because it strengthens the clay. It is reasoned that the increased surface area created by texturing the clay results in faster drying and boosts the strength.



Figure 4-6: Vessels walls after texturing.

The potters at Oriang are in possession of a foot, or measuring tape. However the measuring tape is not used as a reference or guide for shaping the pot. Instead, it is used to occasionally to measure a particular dimension. Exactly what if any action the potter takes from the gathered information is unclear. Similar to the Amilo group, there are no plans or references for pottery design, and all dimensions are determined at the discretion of the potter. The ratio of the major circumference of the pots to their heights ranges from 2.4 to 3.9, with an average ratio of 2.8. Despite the inherent variability in the design they appear to be natural constraints in the forms the pottery is capable of taking. Additionally, volume studies have also shown that many of the pots are within a few liters of containing exactly 40L.

4.4.3 Amilo-Rangwe

The potters at Amilo-rangwe use segmented coiling combined with a stationary technique to form the modified clay pot. A plywood square, roughly a foot square and $\frac{3}{4}$ " thick, is used to support the base of the pot. A piece of plastic wrap from the packaging of

Water Guard bottles is used placed on the square prior to molding to prevent sticking to the board (Figure 4-7) and subsequent cracking due to stress generated between the surface of the clay stuck to the board and inner clay body. The board is then set on a small wheel called a tournette. At the time of our visit, the potters at Amilo only had 3 functioning tournettes.



Figure 4-7: Plastic layer placed between clay and board.

The potter begins molding by taking a fistful of clay and pounding it flat with the palm of her hand, 4-8. Once the clay has spread out to a certain size the potter then pinches the edges, forming the beginning of the vessel wall. The base circumference of fired pots at Amilo-rangwe ranged from 56.5 cm to 77.5 cm. While larger pots tended to have larger base circumferences, the size of the base is largely up to the discretion of the potter. Once the base has been formed, the potter begins to form coils of clay by squeezing the clay into a cylinder shape, and then rolling it to smooth the edges (Figure 4-9). The coil is applied to the exposed edge of the vessel, and then pressed on, forming a join. The material is then pinched and extended upward, and the process is repeated (Figure 4-10).



Figure 4-8: Potter, front, begins forming base. Pounds clay into flat disc.



Figure 4-9: Potter, front, begins extending vessel walls.



Figure 4-10: Continued vessel wall extension. Coiling process repeated.

Once the vessel is roughly half finished in height, the potter smooths the interior and exterior by wetting the surfaces and scraping with an *ombasa*. Figure 4-11 presents the surface before and after smoothing. Once the surface has been treated, the potter continues building up the vessel wall, varying the coil size to control the circumference. From observations during the creation of the pot, the size of the opening of the neck appears to be dictated by the necessary size to give the potter access to the inside. Because there are no set references or specifications for the dimensions of the pot they tend to be left to the discretion of the potter. However, despite this variable aspect of the design, the ratios of the circumference of the belly to the height of the pots range from 2.5 to 3.1.



Figure 4-11: Before and after smoothing. Top photo show discrete layering from coils. In the bottom photo, the distinct layers are obliterated.

4.4.4 Kinda E Teko

Of the three groups the Kinda E Teko group exhibits the most variability. The potters at Kinda E Teko use segmented coiling combined with a hybrid orbital and stationary technique to produce the modified clay pot. Unlike the other two groups, Kinda E Teko possesses no tournettes, and instead relies on sun-baked/fired dishes to support the pottery. The potters work from a standing position, and bend over at the waist, sometimes turning the dish and sometimes moving around to access the pot. Dried leaves are used as lining to keep the wet pottery from sticking to the clay surface, and cracking during drying when the clay contracts (Figure 4-12). Several clay discs were present, at least 3, one for each of the potters present during our visit.



Figure 4-12: Leaves covering clay disc. Leaves protrude from fresh clay base, and prevent sticking.

The Kinda E Teko group primarily produces 40L vessels. The potter begins molding by taking a fistful of clay and pounding it flat with the palm of her hand. Once the clay has spread out to a certain size the potter then pinches the edges, forming the beginning of the vessel wall. The base circumference of fired pots at Kinda E Teko ranged from 48 cm to 60 cm. Unfortunately the group had recently sold their stock at market, so there were only 4 samples available to measure. Once the base has been formed, the potter begins to form coils of clay by squeezing the clay into a cylinder shape,

and then rolling it to smooth the edges. The coil is applied to the exposed edge of the vessel, and then pressed on, forming a join (Figure 4-13). The material is then pinched and extended upward, and the process is repeated. When the vessel is half formed, the surface is first smoothed using an *ombasa* (Figure-14), and then textured using a *kuga*. The potters use a *kuga* made from plastic strapping. Similar to the Oriang and Amilo groups, no designs or references are used to control the size of the pot.



Figure 4-13: Kinda E Teko potter uses coiling technique.



Figure 4-14: Kinda E Teko potter smooths vessel walls.

4.4.5 Summary of Group Techniques

The differences in similarities in the shaping processes used by the groups are largely dictated by the tools available to the groups. The Oriang and Amilo-Rangwe groups have access to nearly identical sets of tools. The only significant difference in the shaping process between the Oriang and Amilo-Rangwe groups is due to texturing, which is the result of the properties of material inputs. In contrast, the differences between the Kinda E Teko group's processes and the other two groups, such as using the orbital technique, can entirely be attributed to the lack of a potter's wheel. A summary of the differences and similarities in the shaping processes is presented in Figure 4-15.

	Technique	Shaping	Wheel	Base	Base Lining	Vessel Size	Use Texturing
Oriang	Stationary	Segmented Coiling	Y	Wood	Plastic	40L	Yes
Amilo-Rangwe	Stationary	Segmented Coiling	Y	Wood	Plastic	20L 40L	No
Kinda E Teko	Orbital / Stationary	Segmented Coiling	N	Clay Disc	Leaves	40L	Yes

Figure 4-15: Summary of Group Techniques.

Chapter 5

Modifications: Decorating, Finishing, and Green Machining

A host of modifications can be made to the ceramic body that maintain the integrity of the form or the functionality of the ceramic. Modifications range from adjustments made to the dimension of the ceramic to coloration of the surface. There are few restrictions as to when modifications can occur in the production process. Depending on the techniques and tools used, some modifications can take place before or after drying, as well as before or after firing of the ceramic. As mentioned in the previous chapter on the shaping of clay, texturing of the pre-fired ceramic surface by potters in the Oriang group occurs before the body has even been fully formed.

There are many methods and techniques for modifying ceramics, and depending on the context and purpose with which they are executed, they can be grouped and classified in different ways. I will primarily focus on the general techniques that are available, and their use in modern and traditional ceramics. A more in depth treatise on the classifications of the different methods of modification can be found in *Pottery Analysis* by Rice.

5.1 Modifications used in Modern Ceramics

Modern ceramics are often used in the mass production of components of larger assemblies. In order to fit properly into an assembly a component may require precise dimensioning. Attempting to mass produce an object whose dimensions are consistent and require no subsequent modification is a complex if not impossible task. A number of variables outlined in Chapter 4 can easily introduce heterogeneities that will affect the

final shape of the object. For components where exact tolerances and specifications are required, it is simpler to control the dimensions by making fine adjustments after shaping using machine tools [7].

The ceramic components can be machined in either their fired or in their pre-fired, green, states. In the fired state, the component is very hard, which makes machining very difficult. Special tools can be used, but are often very expensive and difficult to maintain. In the green state, the ceramic is considerably easier to machine, however the fragility of the object complicates the machining process. During machining, the ceramic must not only be rigidly fixed, but also restrained in a precise and consistent manner without distorting its shape to ensure the accuracy of the process. Additionally, the act of machining can exert stresses on the object that will lead to cracking and chipping [7].

Machining can be conducted through a variety of methods ranging from turning on a lathe to abrasion with a wheel grinder. The process can either be done while the material is wet or dry, depending on the material properties. Machining the ceramic produces considerable wear on the tools used, and maintenance of the tools is required to prevent damage to both the equipment and the ceramic. [7]

5.2 Modifications used in Traditional Ceramics

In traditional ceramics, modifications are made to the body after shaping to alter the dimensions of the ceramic or to finish the surface. In contrast to modern ceramics where modifications generally exist to maintain standards in dimensions, traditional ceramics use modifications as extensions of the shaping process and as tools for controlling the aesthetics of the surface. Modification also serves a reduced role in traditional ceramics for determining the functionality of the object [6].

There are three basic techniques for modifying the shape of the ceramic: beating, scraping, and trimming. Beating consists of repeatedly striking the clay surface. If the surface is supported by another hard object, beating serves to smooth out the surface, thin the walls, and compact the clay. Depending on the shape of the anvil and the striking tool it can also be used to contour the surface as well. If the surface is not supported the technique generally serves to enlarge or change the shape of the vessel. Beating can be performed while the vessel is still wet, until it is nearly leather-hard [6].

5.2.1 Scraping

Scraping is a technique used to thin the walls and remove imperfections from the surface of a vessel. It is often employed as a finishing technique for vessels shaped by the coiling, molding, or pinching techniques. The scraping technique can be employed in a single pass, or used iteratively throughout the shaping process. Any object with a smooth edge can serve as a tool for scraping. Because of impurities and inclusions in the clay, smoothing can scar the surface by dragging particles through the clay. Scraping can be performed before the vessel has fully dried [6].

5.2.2 Trimming

Trimming is a technique for removing excess clay from the vessel in its dry state. The technique is normally used in conjunction with the throwing or molding techniques to refine the edges that are created. In throwing the base may need to be finished by cutting away excess clay, or in molding the surfaces that join to create a seam may be trimmed for aesthetic reasons. Typically a sharp tool, such as a knife, is used to trim the clay [6].

5.3 Finishing Techniques in Traditional Ceramics

Once the shape of the vessel has been finalized, finishing techniques can be used to produce the final surface. Finishing can impart both aesthetic and functional properties to the vessel. In its simplest form, finishing can affect the aesthetic qualities of a vessel by producing a smooth and uniform surface. On a functional level, finishing can also be used to create a simple textured pattern, making the vessel easier to grip. Finishing techniques generally fall under one of two categories: smoothing and texturing [6].

5.3.1 Smoothing

Smoothing techniques are used to create finer and more regular vessel surfaces. They also affect the surface properties of the vessel by altering the density and alignment

of clay particles. Smoothing techniques that involve a few passes or that use soft tools, such as the hands, create surface finishes that are dull and matte. The matte finish is the result of the lack of orientation in the surface particles. Tools with hard surfaces, such as stones, bones, horns, and seeds can be used to burnish the clay surface, creating a surface luster. Burnished surfaces are the result of compaction and reorientation of the clay particles. Burnishing must usually be done while the clay is relatively dry, otherwise shrinkage due to further water loss will usually result in loss of the surface luster [6].

5.3.2 Texturing

Texturing of the pottery surface can serve both utilitarian and decorative roles. The roughening or texturing of the pottery surface may help create a gripping surface or increase the surface area of the pottery allowing for greater heat and water exchange with the surroundings, effecting both the vessels ability to cool its contents or heat them. Gripping surfaces are added to large vessels designed to carry liquids to aid in carrying. Enhanced heat transfer properties are valued in vessels that are employed in cooking. There are two main groups of texturing variants that are classified by the tools used. The first group -Brushing, Striating, and Combing- all use irregular, or serrated tools that are lightly drawn through the surface to generate parallel marks. The techniques can be applied to all or part of the body. The second group of texturing methods consists of three variants: stamping, impressing and rouletting [6,8]

5.3.2.1 Brushing

Brushing uses soft irregular material to mark the surface. Any textured but pliable material such as grass or straw can be wiped over the pottery surface to generate texture. Due to the pliable nature of the tool used, brushing must be executed before the clay has become fully dried. Additionally brushing can be thought of as a type of smoothing technique [6].

5.3.2.2 Striation

Striation techniques used hard-edged serrated or toothed tools to create deeper and more defined textures. Striation can be carried out using shells or chipped stones. To create a regular finish, the potter must apply the strokes in a uniform direction. Because

the tools used in striation are significantly harder than those used in brushing, striation can be carried out while the clay is in either a wet or dry state. Striation can also double as a form of scraping to thin and even out a surface. Combing is a subset of striation where particular detail and attention are given to the patterns created over a small region. For example, the depth of the scoring created by the tool is regularly varied [6].

5.3.2.3 Stamping

In stamping, a die made from any hard object with a specific shape can be used to impress patterns into the clay's surface [6].

5.3.2.4 Impressing

Impressing is a more general approach where patterns from textured surfaces such as textiles or baskets are transferred to the clay surface by application of force [6].

5.3.2.5 Rouletting

Rouletting involves using a circular die that can be rolled across the clay surface imparting a regular pattern [6].

5.3.3 Displacement and Addition of Clay

The techniques described so far have primarily dealt with finishing by superficial modifications made to the clay surface. There are two more groups of techniques that are characterized by either the displacement or addition of clay to modify the surface [6].

5.3.3.1 Displacement

The displacement techniques include both the excision of clay from the body and physical displacement. Techniques for displacement include stamping, impressing, rouletting, punctuation, and cutting. The first three techniques are identical to those mentioned under texturing, and only differ in their local application to parts of the clay surface. The punctuation technique generates depressions in wet clay surface using a

sharp tool. A variety of implements can be used, ranging from a sharp stick to a finger [6].

5.3.3.1.1 Cutting

Cutting is the more complex of the displacement techniques and can be further divided into three subcategories: incising, carving, and perforating. Cutting is defined as the perpendicular motion of the tool with respect to the clay's surface as it is drawn through. Cutting can be performed on the clay in a variety of states ranging from wet and plastic to its sintered state [6].

5.3.3.1.1.1 Incision

Incision is the generation of lines in the pottery surface using a pointed implement. The potter can exert considerable control over the process by factors such as the angle at which the instrument is applied to the surface, the pressure used, and even the direction the tip is drawn [6].

5.3.3.1.1.2 Carving

Carving is a technique where clay is excised from the surface to create a design. Carving can range from simply cutting, to gouging out areas of the clay surface to leave a design in relief or depression. Variations on carving involve the slicing away of sections of the clay body to produce chamfering or fluting [6].

5.3.3.1.1.3 Perforation

Perforation is a technique where the physical wall of plastic or dry clay is breached to create patterns through holes [6].

5.3.3.2 Addition

Additions to the clay surface can consist of either adding more clay material to form new functional or decorative structures or imbedding non-ceramic material into the clay surface. Clay additions to the surface can range from small molded elements termed appliques to larger functional elements such as handles. In order to properly form a bond

between the clay vessel and the clay addition, the two bodies must be in similar states in terms of moisture content. Inlays are normally decorative, and can take the form of any non-ceramic object that has been impressed into the clay surface [6].

5.3.4 Coloring

One of the final modifications made to a vessel is the addition of color. Color is added to the clay surface using pigments. Pigments physically consist of a colorant, fine clay, water, and a binding agent. The water and clay provide a medium through which the colorant is applied, and the binding agent helps stabilize the pigment before firing. The colorant can either be organic or inorganic in origin. Organic colorants represent a broad range of naturally available colors, however they tend to oxidize and burn off during the firing process. Inorganic colorants containing metals can withstand oxidation during the firing process. Only two inorganic pigments are naturally available in abundant quantities for use in pottery: iron and manganese [6].

5.4 Modification Techniques used by the Oriang, Ami-lo-Rangwe, and Kinda E Teko groups

Once the body of the modified clay pot has been finished, there are three stages of modification. The first stage involves decoration of the pottery surface, the second stage involves fixing of the base, and the third stage is the tapping of the clay wall.

5.4.1 Decoration

The first stage, decoration of the pottery surface, is free form, and there are almost no rules or guidelines from a production standpoint for how a potter should proceed. The only modification the potters are restricted from using is puncturing a hole in the clay surface, which would diminish the functionality of the pot. The main types of modification

used for decoration, presented in Figure 5-1, are smoothing, impression, incision, addition, and punctuation.



Figure 5-1: Decoration Techniques. Clockwise from top left: Impression using a kuga, Punctuation using the tip of a kuga, smoothing using the hands, and addition of clay.

5.4.2 Base Modification

The second stage consists of modifying the clay base. During the initial shaping of the clay body the base is not always well defined. Trimming is used to remove excess clay and to square the edges to provide a clean surface (Figure 5-2).



Figure 5-2: Base modification by Amilo-Rangwe potter. Edges of the vessel are trimmed while drying.

5.4.3 Tapping

The third stage, which will be discussed in Chapter 6, is the tapping of the clay vessel. Each of the three groups uses variations on puncturing to form a hole in the clay vessel so that a tap may be installed.

5.4.4 Modifications used by Oriang group

5.4.4.1 Texturing

The potters of Oriang first begin modifying the clay surface through texturing during the shaping process. Before the body of the modified clay pot has been fully formed, the potter roulettes the surface using a *kuga*, which produces a series of ridges and valleys. The *kuga* variant used at Oriang is a small textured metal cylinder approximately an 1/8th of an inch in diameter and is two inches long. The *kuga* obtained commercially. From interviews conducted with the potters it was not clear whether the tool was originally intended for pottery or some other purpose. The lower half of the vessel is textured halfway through the shaping process. During interviews the potters indicated that the texturing helped to strengthen the clay. They also explained that other groups, such as the Amilo-rangwe group, could wait until the entire vessel had been finished because the clay they used was stronger. From our observations, the perceived strengthening of the clay due to texturing could be the result of a faster drying rate achieved through an increase in the surface area.

5.4.4.2 Decoration

Decoration of the modified clay pot is the most elaborate and time consuming at the Oriang pottery group. They use a combination of incision, smoothing, texturing, punctuation and addition. In particular, they are the only group to consistently incorporate addition into the decoration process. Incision is primarily used to generate circumferential bands that are usually found near the neck of the pot. A single band, or multiple parallel bands can be made. The bands are generated with a broken shard of pottery. The potter holds the shard level and then rotates the pottery on the wheel. Smoothing is generally used to repair slight nicks in the surface created during handling, and marks left from the removal of inclusions at the surface. Additional texturing using a *kuga* can be created, but it is usually confined to bands around the circumference. Punctuation using the tip of a *kuga* or a small twig is used to create textured patterns in form of bands near the neck of the pot. The potter can add clay to create elaborate designs that circle the vessel. One of the more common designs created by the potters were images of flowering vines that were built up adding clay to the surface.

The entire decoration process can last up to an hour, depending on the intricacy of the design and the skill of the potter. Though the Oriang group normally uses extensive

decoration, when the group is filling a large order of modified clay pots, they will typically leave the surface unadorned in order to save time.

5.4.4.3 Base Modification

Modification of the base usually takes place a day or two after the clay has had time to dry. A knife is used to trim away excess clay, and then a rock is used to smooth the rough surface.

5.4.5 Modifications used by Amilo-Rangwe group

5.4.5.1 Texturing

The potters of Amilo-rangwe begin modification of the clay surface by texturing once the entire vessel has been completed in the shaping stage of production. Texturing is produced using a *kuga*, and is applied to the lower half of the vessel. The *kuga* is approximately 1/8th of an inch in diameter and two inches long.

5.4.5.2 Decoration

The pottery at Amilo-rangwe exhibits an intermediate amount of decoration compared to the Oriang and Kinda E Teko groups. They primarily decorate the vessel surface using incision, smoothing, punctuation and texturing to create simple geometric designs and banding patterns. Circumferential bands are created using the tip of an old butcher knife. The knife is held level, and the pot is turned on a wheel to produce a level line. Arcs and other sinusoidal patterns that span the entire circumference of the pot are made using incision. One problem inherent in the incision technique, and possibly directly related to the tool, is the creation of too deep a cut that penetrates the surface. One of the modified clay pots at Amilo-rangwe had an incision that penetrated the surface, and would leak excessively if the pot was filled with water. Smoothing is carried out by wetting the surface, and using the bare hand to rub out any imperfections in the surface. Punctuation is used to create textured rings that traverse the circumference of the

vessel. Finally, texturing can also be applied locally to bands around the neck, but it is not used on the entire vessel.

Though significantly less complicated than the designs process used at Oriang, the decoration process at Amilo-rangwe can also take up to an hour to complete. The similarity in the decoration times for the Oriang and Amilo-rangwe groups may be accounted for by the different levels of experience that the two groups have. The group at Oriang has far more experience in terms of age, and the frequency with which they produce pottery than the Amilo group, enabling them to create more complex designs in the same amount of time.

5.4.5.3 Amilo-Rangwe: Base Modification

Modification of the base usually takes place two days after the vessel is formed. A knife is used to trim away excess clay, and then a rock is used to smooth the rough surface.

5.4.6 Modifications used by the Kinda E Teko group

The Kinda E Teko group uses the fewest modification techniques on their pottery wares. Texturing and modification of the base are similar to the Oriang and Amilo-rangwe groups, however comparatively decoration of the surface is limited.

5.4.6.1 Kinda E Teko: Texturing

The lower half of the body is textured using a *kuga* in the middle of the shaping process, before the entire vessel has been formed. Unlike the other two groups, who use a metal based *kuga*, the Kinda E Teko group uses a *kuga* woven from nylon strapping. The differences observed in the physical texturing produced from the two different *kugas* appeared negligible.

5.4.6.2 Kinda E Teko: Decoration

Decoration of the surface uses texturing, impression and incision techniques. Textured bands that traverse the circumference of the pottery are created using a *kuga*.

Additionally bands are created by stamping, using the tip of the *kuga* or a twig. Arcs are generated in a banding pattern as well, using the edge of a flat stone to make incisions in the surface.

The time required for decoration by the Kinda E Teko group was close to half an hour. The short length of time required for decoration can directly be attributed to amount of surface area decorated, and the simplicity of the designs.

5.4.6.3 Kinda E Teko: Base Modification

Modification of the base begins once the pot has been given time to dry. Because the Kinda E Teko group performs the shaping process in a rounded clay disc the bases are rounded and not flat. Smooth stones taken from a local river are used to smooth the base.

Chapter 6

Drying

In the production process drying is the longest step and fraught with difficulty due to the mechanical changes that occur. Drying easily spans time-scales ranging from hours to weeks, and the drying time of an object is not only dependent on its material properties, but on the complexity of its shape as well.

Drying encompasses the transition of the clay from its plastic to its leather hard state. It is during this transition period that defects and cracks can form as stresses build up due to shrinking. Such defects may or may not be immediately visible, but will cause further complications during firing. Drying serves as a critical process in both traditional and modern ceramics, and as a result the processes are virtually identical between the two. The only differences between the drying methods used for each is the sophistication of the techniques.

6.1 Clay-Water System

In order for clay to be shaped and molded it has to be plastic. Plasticity is generated by the addition of water, which hydrates and surrounds the clay particles forming a suspension. It is the physical suspension of the platelets that enables the clay particles to move past each other when force is applied. There are four basic types of water that exist in wetted clay: shrinkage water, pore water, surface adsorbed water, and interlayer/crystal lattice water [6].

6.1.1 Shrinkage

Shrinkage water represents the majority of the water mechanically combined within the clay-water system. Shrinkage water, as the name suggests is directly responsible for

volume loss in the clay during drying. The amount of shrinkage water in a system is dependent on how water is added to the clay. Because shrinkage water physically separates clay particles, a volume loss in shrinkage water corresponds to the same loss in the clay volume. Shrinkage water can be lost directly through air drying, because the water forms a connected matrix in the clay-water system that allows it be drawn to the surface. Once all the shrinkage water from the clay-water system has been removed, air drying effectively halts, and we reach what is called the critical moisture content. The critical moisture content represents the point where subsequent losses in water cause no further shrinkage in volume, because the clay particles are in physical contact with their neighbors. Once the clay particles are in physical contact, the clay becomes rigid and enters the leather hard state [6].

6.1.2 Pore Water

Pore water, as the name suggests, is the mechanically combined water that fills the capillary networks and pores of the clay body. Depending on the porosity of the material, pore water can represent anywhere from 10-26 % of the true volume of the clay body. Loss of pore water has no effect on the bulk volume of the clay, but will register as a weight loss. Because the physical size of the pores and capillaries are very small, pore water cannot simply be lost to the air, and instead must be driven off using heat [6].

6.1.3 Surface Adsorbed Water

Surface adsorbed water constitutes a microscopic film that exists at the boundary between the surface of the clay particles and the atmosphere. Overall it represents a negligible component of the total water in the clay-water system. Additionally it can simply be ignored in terms of the effects it has on volume, and weight loss [6].

The interlayer and crystal lattice water represent water that is bound to the chemical structure of the clay. Interlayer water is present in three-layer clay minerals and is a part of the internal structure. Crystal lattice water is chemically bound to larger clay structures in the form of OH groups [6].

6.2 Drying Defects

Drying leads to the generation of defects in the clay structure through two mechanisms: non-uniform loss of water and non-uniform shrinkage. Though the two mechanisms are inextricably linked, the initial conditions that lead to them differ [6].

6.2.1 Non-uniform Water Loss

Non-uniform loss of water occurs when drying rates exceed the rate at which shrinkage water in the system can be transported to the surface. As the surface dries out, it begins to contract, while the inner layers resist because water cannot be transported away fast enough to accommodate the contraction of the outer layers. Differential contraction in the surface layers generates tension and forms cracks in the clay. Drying rates are dependent on both the clay properties and environmental conditions. Finer clays contain smaller pore spaces that slow the transport of water during drying. Consequently the rate of drying must be decreased in order to maintain a uniform loss of water from the system. Impurities, such as organics in the clay, may also migrate during drying and form residues on the surface. These residues can then inhibit water loss [6].

Environmental factors such as the sun and wind will result in the non-uniform loss of water. Letting the clay dry in the sun, will cause the surface directly exposed to the sun to dry faster than the unexposed surface. The differential drying will cause cracking and warping in the clay body. Similarly exposure to wind will cause increased drying rates on the exposed surfaces, leading to warping and cracking. As a result drying will often occur in a sheltered location, in order to minimize variations in environmental factors [6].

6.2.2 Non-uniform Shrinkage

Non-uniform rates of shrinkage in clay may be caused by uneven distribution of water, and the orientation of clay particles. Water content within the clay body may be unevenly distributed due to insufficient mixing or because of physical interaction with the clay. During preparation, if the clay is not given sufficient time to set or is not mixed

enough to eliminate heterogeneities then water content will vary. Regions that are wetter will contract more, compared to regions that are relatively dry. The difference in the contraction in the two regions will lead to warping and cracking. Similarly, clay that has been repeatedly stroked or smoothed during the shaping process will tend to contain more moisture. This is particularly noticeable in thrown pottery, where the outer surface due to shaping exhibits a higher water content than the inner surface [6,7].

The orientation of clay particles is an important factor determining how much shrinkage will occur in a given direction. Clay particles tend to exist as platelets, having a pronounced length but very small thickness. If the clay particles are randomly oriented, then shrinkage will occur uniformly in all directions and will be isotropic. However, if the particles are aligned to a particular orientation they will stack in layers, and shrinkage will preferentially occur perpendicular to the layers as water is removed between them (Figure 6-1). Particle orientation can occur as the result of applied force during smoothing or burnishing. Such orientation is visible in burnishing because of the resulting luster that is generated [6].

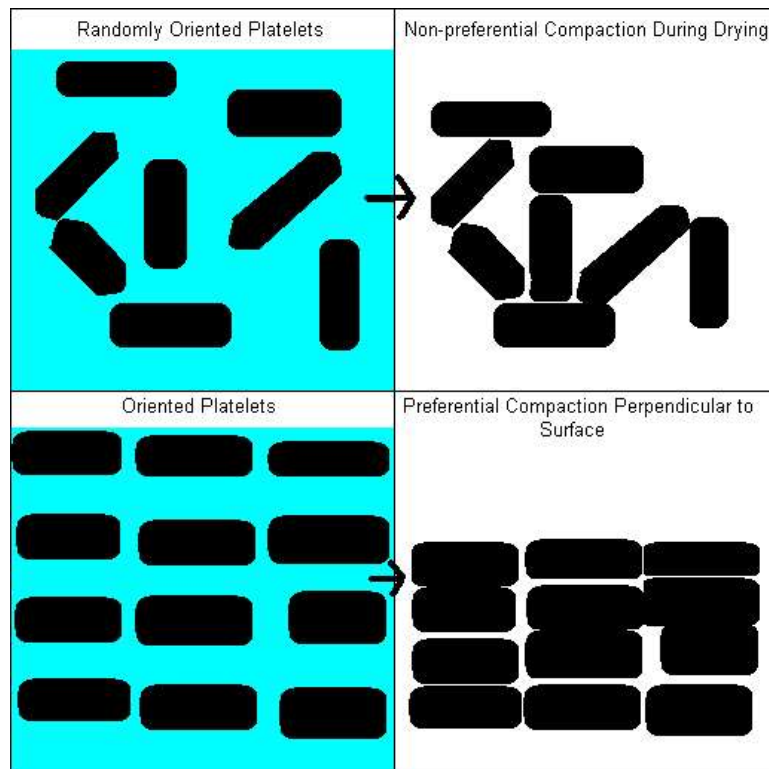


Figure 6-1: Closeup of drying clay-water system. Pronounced drying perpendicular to surface of oriented platelets.

6.3 Controlling Defects

Defects can be limited by controlling both the drying process and by limiting the amount of shrinkage that takes place. The drying process can be strictly controlled through temperature, humidity and air current. In a modern technique known as humidity drying, the clay is heated in an environment where the humidity prevents evaporation of water. The drying process is then controlled by incrementally lowering the humidity until all the shrinkage water has been driven off. Physical characteristics such as particle size and orientation can be used to minimize shrinking. By mixing fine and coarse clays, shrinking can be reduced. Orientation effects can be reduced by the addition of deflocculating agents [6,7].

6.4 Drying processes used by the Oriang, Amilo-Rangwe, and Kinda E Teko potter groups

Drying time and techniques are almost completely uniform between the three pottery groups. With the exception of the structures that the pottery is stored in while drying, the techniques and methods are identical. Once the clay has been shaped, and subsequent modifications finished, the modified clay pot is moved along with the base, either a board or dish, to the storage place. At Oriang, an entire room is dedicated to the storage of drying pottery (Figure 6-2). At Amilo-Rangwe the pottery is stored in a corner of the community building. At Kinda E Teko, the pottery is stored in one of the shacks. The rooms serve to keep the pottery from being exposed to direct sunlight, wind, and rain. A wet cloth is sometimes placed over the opening of the pottery to prevent it from drying out too fast. After the modified clay has been allowed to sit for a couple days, the base is modified to increase stability and aesthetic and the vessel is inverted and allowed to dry. Complete drying times can range from a couple weeks during the dry seasons to over a month. Longer drying times can be the result of humid weather and the rainy season which necessitates longer drying periods to compensate for the decreased drying rate, or because the potters are waiting for a sufficient number of dried vessels to begin firing.



Figure 6-2: Vessels drying in Oriang storage room.

Chapter 7

Tapping

One of the key features of the modified clay pot is the use of a spigot to access water stored in the vessel. In order to attach a spigot, an opening must be made in the vessel wall. A location for the spigot is chosen near the base to maximize both the amount of stored water that is accessible and access to the tap. Installing the tap some distance from the bottom is preferred to limit the amount of settled material that may be drawn into the tap.

There are two practical points during the pottery making process at which an opening can be made: before or after firing. Creating an opening in the vessel wall before firing has the advantages that the clay is still relatively soft and malleable. No special tools are required to penetrate the surface. The opening can be made using a finger or a specialized tool. Also prior to firing the clay can still be resurfaced and shaped, allowing the opening to be smoothed to eliminate any irregularities. However, the opening must be made to compensate for shrinkage that will occur during drying and firing. Adjusting the opening prior to firing to compensate for shrinkage is complicated by the fact that different clays and clay mixtures exhibit different amounts of shrinkage. In contrast creating the opening after firing eliminates the difficulties associated with having to accommodate variable shrinkage. However, after firing the ceramic is in a very hard and brittle state. Tools are required to create an opening, and the forces and stresses associated with tapping the hardened material may aggravate pre-existing flaws formed during drying and firing, or introduce new ones. While both tapping prior and after firing appear to be viable techniques, only techniques for tapping prior to firing have been developed by the three groups.

7.1 Tapping Techniques used by the Oriang Group

The Oriang group taps their vessels after waiting a few days for them to dry. In general the dryer the pottery is, the less shrinkage the pottery can further undergo. It is not known how frequently the critical moisture content in the pottery is reached before tapping begins. A hollow plastic frustrum is used to create the opening (Figure 7-1). The tool is approximately 4.5 inches long, and has a minor diameter of .875 inches, and a major diameter approximately 1.75 inches. The tool is held parallel to the ground about its axis of symmetry, its hollow tip is placed on the surface and force is applied to cut out an opening. The tool can then be pushed further into the vessel to widen the opening. Measurements made on fired vessels that had yet to have a tap installed demonstrated that the opening size could range from 2.5 to 5.5 cm. This range easily accommodates the 1-inch diameter PVC piping used in attaching the spigot.

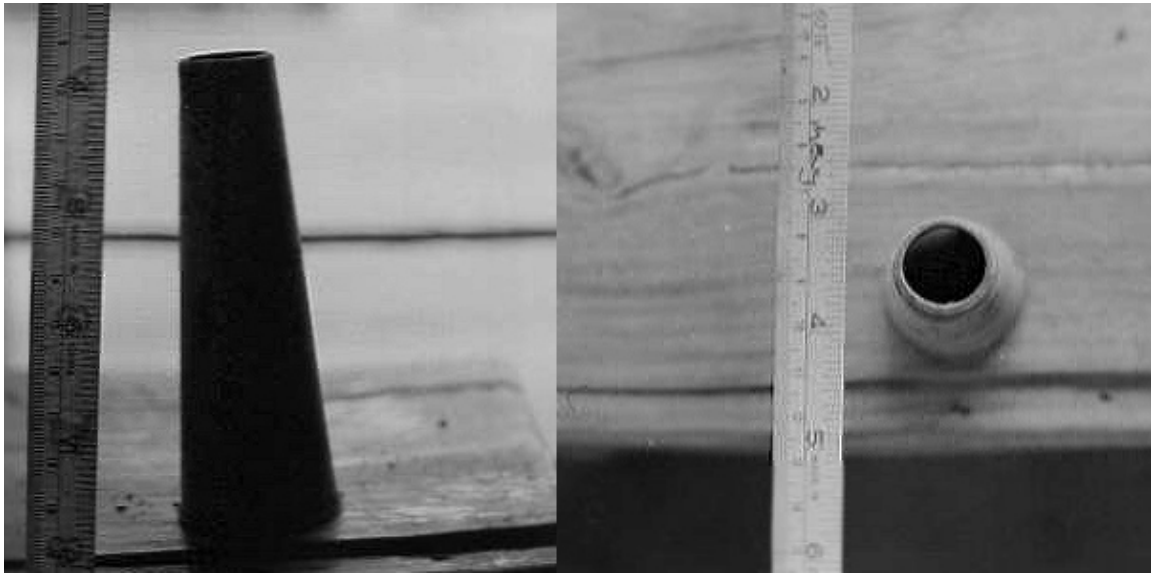


Figure 7-1: Profile and aerial view of Oriang tapping tool.

7.2 Tapping Techniques used by the Amilo-Rangwe Group

The Amilo-Rangwe group taps their vessels after first allowing them time to dry. The durations the pottery is allowed to dry are not uniform between tapplings, but the more drying that occurs before tapping, the less shrinkage the opening will undergo. The physical tubing that is used in attaching the spigot to the pottery is also used to create the opening (Figure 7-2). A piece of 1 inch outer diameter, 1/8 inch thick PVC is used to make the opening. The tube is held perpendicular to the surface, and then gently forced through to create the opening. The potter then further widens the opening by using a knife. The knife is inserted and rotated, removing material from the edge until the full width of the knife is accommodated (Figure 7-3). Measurements taken from the openings

of vessels after firing ranged from 2.5 to 4 centimeters in diameter. This range of opening sizes easily accommodates the 1 inch diameter PVC tubing used in attaching the spigot.



Figure 7-2: Amilo-Rangwe potter tapping a clay vessel. Potter uses 1" diameter PVC tubing to create initial opening.



Figure 7-3: Tap opening widened using a kitchen knife.

7.3 Tapping Techniques used by the Kinda E Teko Group

In contrast to the other two groups, the Kinda E Teko group begins taping before the pottery has had significant time to dry. They use the same 1" outer diameter PVC to tap the vessel wall, as is used to attach the spigot (Figure 7-4). The tube is held parallel to the ground and pushed through the clay to form an opening. However, unlike the other two groups no significant widening of the opening takes place after this step. Sometimes the tubing is then left in place for a day to prevent further shrinking during drying (Figure 7-5). Once the pottery has finished air drying the opening is checked to make sure it will accommodate the PVC tubing. If it is too small, the lower half of the pot can be soaked for half an hour, making the surface malleable, and the opening can manually be widened through smoothing. The Kinda E Teko method of tapping produced the smallest range of diameters, spanning 2.5 to 3.0 cm. The group uses the same 1" outer diameter, 1/8 thick PVC for attaching the spigot as the other two groups.



Figure 7-4: Tapping at Kinda E Teko. Potter uses 1" diameter PVC tubing.

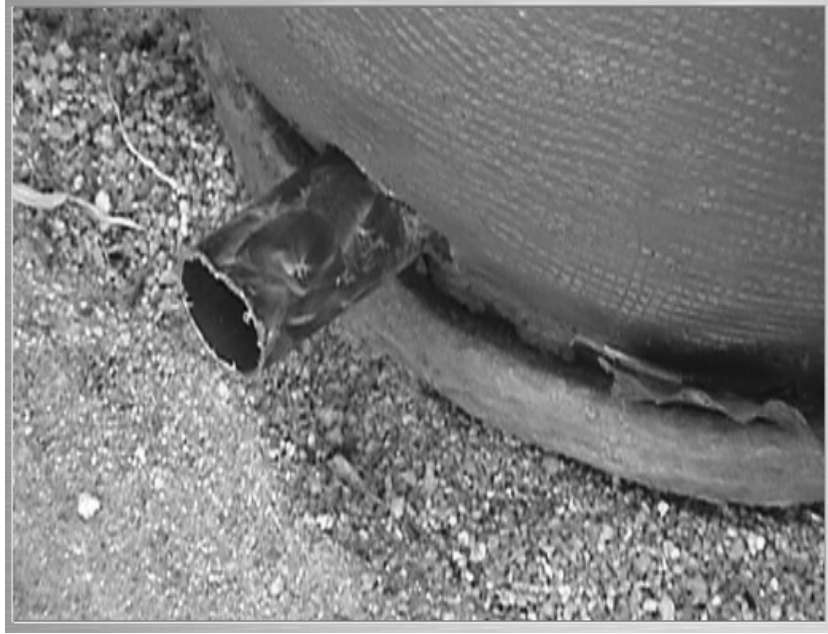


Figure 7-5: Tube left in opening while vessel dries.

Chapter 8

Firing

Prior to firing, the previous stages of production have primarily focused on mechanical changes to the clay. Water and tempers are added to the clay to adjust mechanical properties, such as plasticity. Once the clay has been prepared, it is shaped into a desired form using an appropriate technique, and then allowed to dry. The initial drying results in some stabilization of the clay body, however the structure is rather weak and subject to deformation from external forces. The firing stage of production represents a chemical change in the structure of the clay through bonding that results in stabilization and strength of the body [6].

8.1 Densification

Firing is a densification process, and falls under the more formal heading of sintering. Sintering encompasses all methods used by traditional and modern ceramics. The two divisions take very different approaches to the densification process. Modern ceramics takes a molecular view of the chemical changes that occur during densification, while traditional ceramics is more concerned with macroscopic properties such as hardness and aesthetic [6].

8.2 Sintering in Modern Ceramics

In order for sintering to occur two conditions must first be met. There must exist some mechanism by which material within the ceramic can be transported, and an energy source must exist to activate and sustain transport. Sintering can occur through a variety of mechanisms that utilize different sources of energy. In general transport can occur through diffusion or viscous flow of material. Typically the energy source is heat. The entire process of sintering is a continuum of change as particles begin to reorient and

bond to their neighbors. Despite the lack of distinct transitions, the process of sintering can roughly be divided into 3 stages [6].

8.2.1 Particle Rearrangement and Reorientation

The first stage of sintering consists of slight rearrangement and reorientation of particles, as they attempt to minimize free surface area by creating contacts with their neighbors. The first stage of sintering is also characterized by the formation of necks between particles as contacts merge to minimize surface area. The physical drive to minimize surface area stems from the minimization of the free surface energy, producing a more stable state [6].

8.2.2 Decreasing Porosity and Shrinkage

The second stage of sintering is characterized by continued neck growth, decreased porosity, and movement of grain boundaries, which result in shrinkage of the ceramic. Particles continue to merge and converge as they attempt to minimize free surface area. As a result porosity begins to decrease and the material begins to compact. The majority of shrinkage that occurs during sintering is the result of the second stage. Transition from the second to third stage is effectively marked by the breakdown of the continuous capillary network within the ceramic, and the isolation of pores [6].

8.2.3 Removal of Porosity

The third stage of sintering consists of the final removal of porosity. A liquid phase can form in the vessel due to the addition of heat, filling the pore spaces and resulting in complete densification. While complete densification is possible under the proper conditions, pores that are trapped in grains and removed from the grain boundaries are inaccessible and unlikely to be removed. [5]

8.2.4 Controlling Sintering and Densification

Sintering and the resulting densification can be controlled by a number of parameters that include the composition of the material, the particle size distribution, the temperature, and the temperature duration. The effects each of these parameters has are outlined in Chapter two, which covers processing of material [6,7].

8.2.5 Defects from Sintering

A number of defects can result from the sintering process, and while some of these defects are easily detectable, others require specific techniques and knowledge to identify. Two basic defects that can occur are warpage and overfiring [6].

8.2.5.1 Warpage

Warpage is one of the most common defects to occur and often results in the rejection of components. Warpage can be caused by heterogeneities in the material or insufficient support during sintering. Heterogeneities left over from processing or introduced during shaping result in density variations that subject the ceramic to uneven forces. Insufficient support during firing may allow the ceramic to shift under its own weight. Density variations cannot be corrected for during sintering, and must be accounted for during material preparation and shaping. Warpage due to shifting in the weight of the ceramic can be amended by providing supports. Supports made from refractory materials known as saggars can be used to restrict movement of the ceramic and prevent warping. The two types of warpage can be distinguished at the microscopic level by examining structure. Warpage due to density variation will exhibit variation in the microstructure, while warpage due to insufficient support will exhibit a constant microstructure [6].

8.2.5.2 Over-firing

Overfiring can lead to a number of defects through vitrification of the ceramic. Vitrification of the ceramic occurs when the energy from heating allows the material to enter a malleable state. During this malleable state, the ceramic can warp under its own

weight. Bloating or blistering of the surface can also occur due the build up of volatile gases underneath the vitrified surface. Normally volatile materials such as organics are driven off during firing and allowed to escape through the pores of the ceramic. However, if the surface layer has become plastic and fused, gases will build up and distort the surface [6].

8.3 Sintering in Traditional Ceramics

The same rules and processes that govern the firing of modern ceramics are also generally applicable to traditional ceramics. However in traditional ceramics, especially as it practiced by indigenous groups, the tools and the technologies necessary to properly control and manipulate sintering are not available. Properties such as complete densification are never achieved. Instead, rudimentary techniques that have been successfully employed over thousands of years are used to fire their wares to a hardened state [6 ,8].

8.3.1 Traditional Firing Methods

Traditional methods for firing pottery can be divided into two groups: non-kiln based and kiln-based. Non-kiln based firing techniques are also referred to as open firing, bonfire, and clamp methods. Non-kiln techniques are usually characterized by short firing times that can range from minutes to hours, and low firing temperatures compared to those achieved through using kilns [6].

8.3.1.1 Non-kiln Firing

The specific details for how a non-kiln firing is conducted can vary considerably between the groups who conduct the firings, and the particular purpose it is being used for. In general non-kiln firings consist of 3 layers: a bed of fuel, the pottery, and an additional covering layer of fuel. The fuel bed is placed directly on the ground, and consists of slow burning items. Large and thick fuels such as branches and wood are generally used in this layer. The fuel bed provides the majority of the heat that reaches the pottery. The next layer consists of the pottery that is to be fired. This technique is

scalable, and can easily be adapted to accommodate a single pot or many by adjusting the amount of fuel used. On top of the pottery a covering layer is added. This covering layer can consist of a faster burning fuel such as grass or it can consist of the same material as the bed layer. The covering layer acts as insulation to trap heat generated by the slower burning fuel in the bed. Ignition of the fuel can either begin at the bottom or top layer. More fuel can be added at any time during firing, simply by tossing more fuel on top. Once the fuel has burned out, the firing is over and the pots can be removed with or without waiting for them to cool [6].

8.3.1.2 Color Indicators

Color indicators are used to determine whether the pottery was fired to completion. During firing, heat transferred to the pottery is radiated at visible wavelengths, and an observed glow can be indicative of the temperature of the pottery. Additionally chemical reactions that occur due to oxidation result in color change and can be used as indicator that process has gone to completion [6].

8.3.1.3 Non-kiln firing Efficiency

Though non-kiln firing is desirable because it provides a simple and economically viable means for producing low-fired pottery, it is not without its disadvantages. In particular non-kiln firing techniques are highly inefficient. The heat generated by the top layer is almost entirely lost to the atmosphere through radiation and convection. It has been estimated that only 10% of the available energy in open firing goes directly into sintering of the ceramic [6].

8.3.1.4 Controlling the Firing Process

Lack of control over the firing process is another inherent drawback to non-kiln firing. The physical setup of a non-kiln firing combined with the amount of heat that is produced precludes access to the fuels. As a result, there are few options available for controlling the temperature during firing.

In order to drive the proper chemical reactions, firing needs to reach a temperature around 600 degrees Celsius. While open fires may reach temperatures around 1000

degrees Celsius, the duration the fire spends at the temperature and temperature that the pottery actually reaches are highly variable. Two methods for affecting the temperature of a non-kiln fire are adjusting the initial amount of fuel used and covering the fire with a layer of fuel or ash. While these methods do provide some coarse control over the temperatures reached, they are unable to provide any fine adjustments. Non-kiln firings are typically characterized by very rapid changes in temperature as fuel is consumed. The sharp change in temperature that occurs during firing can lead to thermal stressing in the pottery, which can cause defects such as cracking. The risks associated with thermal stressing can be reduced by preheating the pottery prior to firing. Spatial variations in temperature during firing can occur due to the placement of fuel, and the availability of oxygen, which leads to the non-uniform consumption of fuel. Spatial variations in the temperature can also lead to thermal stressing [6].

Non-kiln firing also affords very little protection to the pottery from both the weather and the firing itself. While conditions such as rain can easily prevent or interrupt a firing, more problematic are the effects of winds. Strong winds have the potential to change the temperature during firing by over 200 degrees Celsius. Such large changes in the temperature, especially over a small portion of the pottery can generate large thermal stresses and ruin entire batches of pottery [6].

8.3.1.5 Damage from Firing

The firing process though necessary for sintering, can have negative impacts on the pottery. In non-kiln firing, the pottery is situated directly in the fire. Direct exposure to the flames and fuel can lead to undesired marking to the surface. Another consequence of the direct placement of the pottery on the fuel is that as the fuel is consumed the structure can shift and change. While the shape is not particularly important to the firing process, dramatic shifts in the understructure of the fuel can lead to movement of the pottery and result in cracking and denting [6].

8.3.2 Kiln Firing

Kilns represent a significant technological advance in pottery. Unlike other tools and techniques that enabled potters to produce more complex designs and items, kilns

provide a substantial amount of control over the physical firing process and reduce the risks normally associated with firing. A kiln is essentially an enclosed chamber used to contain the firing process. The enclosed chamber serves to separate the firing process from the environment and to channel heat produced from combustion. Because the process is contained, higher temperatures can be reached and sustained during the firing process. The sustained temperatures lead to more consistent and thorough heating of pottery, which reduces thermal stress associated with uneven heating and dramatic temperature shifts. The kiln structure is composed of non-refractory elements, such as stone and brick, that can withstand cyclic thermal stressing associated with firing and cooling of the structure [6].

There are three basic types of kiln: pit, updraft, and downdraft. Though all three types of kilns use the same general principle of containment of heat they represent improved sophistication in the firing process by removing the pottery from the physical firing [6].

8.3.2.1 Pit Kilns

Pit kilns is the simplest of the three types of kilns. Though not a true closed structure, the pit kiln represents a shift towards separation of the firing process from the environment. The pit kiln consists of three or four walls, placed around a plot of bare earth. The walls are relatively low, and consist of either dried mud or fired bricks. Similar to a non-kiln firing, the pottery is sandwiched between two layers of fuel. The pottery is placed on a bed of slow burning fuel, and then covered with an additional layer of slow or fast burning fuel. The walls serve to partially contain the heat produced from firing, which leads to longer saturation of higher temperatures. A variant of a pit kiln can be constructed on a slope. The convection generated by the gradient in temperature along the slope, helps create drafts that aid in firing. The drawbacks inherent in using pit kilns are very similar to those observed in open firings. Overall the efficiency of the pit kiln is improved by containing the heat, but a significant amount of heat is still lost. The pottery is also directly exposed to the firing process and subject to the non-uniform temperatures resulting from uneven combustion of fuel [6].

8.3.2.2. Updraft Kilns

The updraft kiln is essentially a fully enclosed pit kiln. The firing process and pottery are fully contained within a chamber. The fuel and pottery are located in separate compartments. The fuel is housed at the base of the kiln. Fuel can either be fed through openings at the side of the base, or through a special fire box that sits below and forward of the firing chamber. The pottery is housed in a chamber directly above the firing chamber. The pottery and fuel are typically separated by a grate structure, which allows the passage of heat and gases through the kiln. Depending on the design of the kiln, the pottery can either be top loaded into or side loaded into the top chamber. In the case of a top-loading chamber, gases and heat are allowed to escape through a perforated covering. For a side-loading chamber the heat and gases are typically released through a chimney structure [6].

The advantages of the updraft kiln are the separation of the pottery and fuel, and the improved efficiency of the firing process. The compartmentalized design of an updraft kiln serves to remove the pottery from the firing process. By separating the pottery from the fuel, the risks associated with pottery shifting due to fuel consumption are eliminated. Additionally by removing the pottery from direct contact with the heat source, the risk of heat shock is reduced. Firing efficiency is improved by further containment, reducing the amount of heat that is directly lost to the environment and increasing the amount transferred to the pottery. Additionally, the chambers eliminate the need for a covering layer of fuel to help insulate. Because the majority of the heat produced from the covering layer of fuel is lost to the atmosphere, this helps to reduce the amount of fuel needed. Drawbacks to kiln in general include over firing due to hot spots that can form in the pottery chamber. Additionally, the pottery closest to the fire is subjected to large amounts of thermal stressing [6].

8.3.2.3 Downdraft Kilns

The downdraft kiln design completes the separation of the pottery from the firing process. Heat from the firing source is directed to the pottery using a junction between the two chambers. The firing and the pottery chambers are no longer constrained to be physically stacked. Heat from the fire rises to the top of the chamber, and then is

deflected downward and channeled into the pottery chamber and then vented out. The redirection provides more time for mixing, creating a more uniform firing process. Increased mixing prevents the generation of hot spots that normally form in an updraft kiln. Direct heat loss to the atmosphere due to convection is also minimized because of the downward path the heat is forced to take through the pottery chamber [6].

Despite the overall improvement in the firing process that kilns provide, they have considerable drawbacks. The primary drawback is the cost. Kilns represent a substantial financial and time investment on the part of the potter. Second, though kilns do offer increased efficiency and reduced fuel needs, they only achieve 30% to 40% efficiencies. Third, though kilns do remove considerable amounts of variability from the firing process, heat gradients in the pottery chamber still persist, and have the potential to cause under or over-firing [6].

8.4 Firing Processes used by the Oriang, Amilo-Rangwe, and Kinda E Teko Groups

8.4.1 Open Firing

The three pottery groups primarily rely on open firing techniques to sinter their pottery. Due to time constraints, I was only able to document the firing techniques employed by the Oriang and Amilo-Rangwe pottery groups. Overall, the processes between the two groups are very similar, only varying on minor accounts.

8.4.1.1 Location

Of the three groups only the Kinda E Teko has a designated location for firing pottery. The Kinda E Teko firing site is located on the personal property of the potters and is situated on the opposite side of the property as the potter's residence. Presumably, the firing site is located there to minimize the effects of smoke produced from firing. The site is marked by ash left over from previous firings.

The Oriang group, due to the extensive size of their compound, and lack of residential structure in the vicinity of the workshop, has multiple locations for firing pottery. During times of peak production, multiple firing sites are used.

The Amilo-rangwe group is the most crowded for space in terms of firing sites. Their workshop sits in proximity to a brick foundry. The two groups share what public space is available for firing bricks and pottery. As a result, the Amilo-rangwe group does not have a designated site for firing their pottery. Additionally, because many of the potters work independently, they fire their wares at home.

8.4.1.2 Fuels

Fuels used by the three groups range from grasses and woods to animal dung. Slower burning fuels, such as branches, are used as a base or placed in direct contact with the pottery. Faster burning fuels such as grasses are then used to add a covering layer.

8.4.1.3 Building the Fire

The Oriang group builds their fire on a base of bricks and pottery shards (Figure 8-1). The pottery is then covered with a layer of branches forming a conical shape. The wood is then entirely covered with a thick layer of grass (Figure 8-2).

The Amilo-Rangwe group builds their fire on a bed of branches. The pottery is placed directly on the bed, and then another layer of branches are placed on top. A final layer of grass is then added, covering the mound of pottery and branches (Figure 8-3).



Figure 8-1: Brick mound. Used for open firing at Oriang.



Figure 8-2: Oriang fire building process. Chronological order: top left vessels are stacked on the brick bed. Top right, slow burning fuel placed on top. Bottom left, more stacking of slow burning fuel. Bottom right, additional covering layer of fuel is added.



Figure 8-3: Amilo-Rangwe fire building process. In chronological order: top left, bed of slow burning fuel created. Ttop right, pottery vessels stacked on fuel. Bottom left, addition layer of slow burning fuel placed on vessels. Bottom right, fast burning fuel added as covering layer.

8.4.1.4 Preheating

Of the two firings observed, only the Amilo-Rangwe group preheated their pottery. Potters used hand-held bundles of grass to heat the pottery surface (Figure 8-3) burning grass were also placed inside the pottery as well. Preheating lasted several minutes, and was performed immediately prior to firing.



Figure 8-4: Pre-heating Pottery. Amilo-Rangwe potters preheat pottery before firing to reduce the thermal stress.

8.4.1.5 Ignition

The fuel is then ignited from the top using lit bundles of grass (Figures 8-5, 8-6). As the top layer begins to turn to ash, additional fuel in the form of grass or wood is added. Temperature measurements during firing were taken at Amilo-Rangwe using a TIF7000 pyrometer, with a contact probe with temperature range of -46 degrees to 1090 degrees Celsius. A peak temperature above 1090 degrees Celsius was recorded before the probe melted, which prevented any further temperature measurements at any of the groups.



Figure 8-5: Oriang firing.



Figure 8-6: Amilo-Rangwe firing

The Oriang firing only lasted 6 minutes and the Amilo-Rangwe firing lasted nearly 30 minutes. The potters gauge the success of the firing once the pottery had been re-

moved, the two groups used pottery color as an indicator. The Amilo-rangwe group looked for a red color, and the Oriang group looked for a brown color. Once a piece of pottery had been deemed satisfactorily fired, it was sealed using surface treatments and given time to cool. If not, the pottery was either placed back in the smoldering ashes, or refired at a later time and date.

8.4.2 Kiln Firing

Of the three groups only the Oriang group has immediate access to a kiln. Purchased with funds from a UNIDO grant, the updraft kiln is located at the rear of the compound. The kiln uses a vegetable oil based fuel as an alternative to wood and grasses. Vegetable oil represents a constant and easily renewable bio-fuel that takes advantage of agricultural production within the region. However, the kiln has fallen into disrepair. In interviews with group members, they had mentioned that the kiln was too fuel intensive to use for every day firing. Additionally, I believe the kiln may have been too technically advanced for the group to maintain on its own. However, from discussions with some group members, I learned the kiln chamber is occasionally used for firing. Fuel and the pottery are placed in the chamber in an ad hoc fashion and then fired.

Chapter 9

Sealing

9.1 General Sealing Techniques

A number of techniques can be applied to the ceramic vessel after firing to alter the surface permeability. In modern ceramics, porosity can easily be controlled through material properties and densification. In traditional ceramics, especially as it practiced by indigenous groups, there is limited access to the technological resources employed in modern ceramics. The porosity is very difficult to control as it is dependent on material properties and firing conditions. As a result, simple post-firing treatments are used to reduce surface permeability.

Post-firing treatments generally consist of applying organic materials to the vessel surface immediately after firing. A variety of organic substances ranging from tree resins to beeswax are used by various indigenous groups in post-firing treatments. The treatment can be limited to either the interior or exterior surfaces. Reduction in the surface permeability is desired for vessels for that will be used to store liquids and is not suited for all pottery vessels. In particular, treating cooking ware may reduce the heat transfer properties of the ceramic by limiting conduction through saturated pores in the ceramic [6].

Two post-firing techniques for sealing pottery are used by the pottery groups. The first technique is applied immediately after firing, and is used by all three pottery groups. The second technique is more generally used as a home remedy for pottery that is too porous.

9.2 Orwech

During firing, bark from *orwech*, a Luo name for a local tree, is boiled in water (Figure 9-1). Boiling the bark releases resins that color the water red. Once the firing has finished, the *orwech* solution is applied to the still hot pottery surface. The solution is applied using small leaf covered branches from *sulferia*, a local plant, or brush (Figure 9-2). Using a combination of direct strokes and flicks, the solution is applied to the exterior surface. The *orwech* solution boils off on contact with the pottery, leaving black markings behind. The sealing process continues until the pottery is sufficiently darkened or until it becomes cool. It appears the resin is deposited on the surface after the water is boiled off and reduces leaking by sealing pores on the pottery surface.



Figure 9-1: Solution of boiled *orwech*. Used by Amilo-Rangwe potters for sealing pottery.



Figure 9-2: Application of *orwech*. Amilo-Rangwe potter uses branch to apply *orwech* sealant to hot vessels.

9.3 Corn Porridge

The second technique was related to us in multiple discussions with members from the different pottery groups. Occasionally when a vessel used for storing liquid is too porous, a hot porridge of corn flour is made and then applied to inner surface. After application, the vessel and porridge are then left to sit for a day. The porridge is then removed, and the vessel can then be used to store liquids. It is speculated this technique reduces leaking by physically obstructing the vessel pores and channels with fine corn flour grains.

Chapter 10

Tap Preparation and Attachment

10.1 General Tap Background

The preparation and attachment of the tap to the vessel wall is one of the most complex stages of production, requiring multiple components to be assembled into a single unit. While the processes required to prepare and to attach the taps are simple, especially when compared to the techniques required to process and shape the clay, they represent a completely new skill set for the three pottery groups that needs to be developed and explored.

The concept of attaching a tap to a pottery vessel is not unique to the modified clay pot. CARE Kenya originally developed the idea of the modified clay pot from potters who occasionally took requests to produce vessels with a tap attached. The inherent difficulty is not in developing techniques that are capable of attaching a single tap successfully, but in developing techniques that are capable of being scaled to levels of mass production. The entire process can be divided into two stages: preparation of the tap, and physical attachment to the vessel.

10.2 Tap Preparation

A tap must first be modified slightly by extending the length of its body before it can be attached to the vessel. Currently all three groups use a variable length of PVC tubing with $\frac{7}{8}$ " inner diameter and 1" outer diameter. Extension of the tap length is required to accommodate the physical space needed to interact with and operate the tap and to secure a sufficiently strong join between the tap and the vessel. The tap is attached near the base of the vessel to maximize the amount of the water that is accessible. Curvature near the base of the vessel combined with the vessel's thickness,

approximately 1 cm to 1.5 cm, require the tap's threaded end be longer in order to install the tap level to the ground. Additionally, taps with levers for handles cannot function if they are installed too close to the vessel surface. Strength requirements are also an issue. Because the tap extends beyond the surface of the vessel it is prone to be jostled, bumped or even used as a grip. A minimal amount of extension beyond the vessel interior and exterior and required in order to properly cement the fixture in place. The size of the PVC extension is variable, usually ranging from 6 cm to 10 cm. The Oriang and Amilo groups use a reference, such as another pre-cut piece of tubing or a measuring device to gauge the length of the pipe. The pipe is then cut using a hacksaw blade (Figure 10-1). The Kinda E Teko cuts the length specific to each vessel. A long section of pipe is cut and then placed in the tap opening in the vessel wall. The pipe is then trimmed with a hacksaw blade until the proper length is reached.

Once the tubing has been cut to the proper length it must be fitted to the tap joint.

The taps used by the three different groups vary by model and brand. Two different sizes of taps are used: $\frac{1}{2}$ " and $\frac{3}{4}$ " outer diameter. The Amilo-Rangwe and Oriang groups almost exclusively use the larger taps, despite increased costs, to increase flow rates. The Oriang and Amilo groups use a crude form of press fitting to attach the tubing to the tap (Figure 10-2). A small fire is used to heat gently the end of the pipe (Figure 10-2). The pipe is then pressed over the threading of the tap joint. This process is repeated until the pipe fits snugly over the threads (Figure 10-3). On the final pass the Oriang potters coat the threads in a rubber cement compound to ensure a good seal is formed. In contrast, the Kinda E Teko group cuts a $\frac{1}{2}$ cm vertical notch in the end of the pipe and press fits it to the tap joint (Figure 10-4). The notch relieves tension allowing the pipe to spread to accommodate the threading. Though the fitting achieved by the Kinda E Teko method is not as tight a fit as those achieved by the Oriang and Amilo methods, it appears to be just as functional. Once the tube is attached, the tap is ready to be joined to the vessel.



Figure 10-1: PVC tube cut to length. Oriang putter cutting PVC tubing to length with a hacksaw blade.



Figure 10-2: Thermal press-fitting. Oriang potter heating PVC to press fit to tap threads.



Figure 10-3: Fitted tap. Press-fitted PVC tubing to tap threads using thermal press fitting at Oriang.



Figure 10-4: Closeup of split PVC pipe. Used by Kinda E Teko potters to fit tap to PVC tubing.

10.3 Tap Attachment

Techniques for attaching the tap vary significantly amongst the three groups. While the overall approach of using cement to attach the tap to the vessel is similar among the three groups, it is the level of efficiency that the techniques achieve that distinguishes them from one another.

10.3.1 Oriang

The Oriang group has the most time-efficient technique for attaching the tap to the vessel. A single potter works on several vessels in parallel (Figure 10-5). To prevent cement from clogging the tap during fixing, the end of the PVC tube is stuffed with plastic or cardboard. The vessels are placed on a bench, and the modified tap is inserted into the opening. The taps are then wedged into the openings, using clay shards and vessels to prop up the tap. Because the opening is made near the base where the surface is tilted, wedging the tap in the opening only produces a minor tilt, allowing it to remain roughly parallel with the ground (Figure 10-6). Several vessels are secured in succession. A 1-to-1 mixture of cement and sand referred to as “*nill*”, a local term for the substance, is mixed with some water and used to fix the tap in place. Attachment of the tap occurs in two stages over the course of two days. In stage 1 only the opening and a small region around it in the exterior and interior are covered in *nill*. This initial deposit of *nill* serves to stabilize the tap and fix it in place (Figure 10-7). Once it has been allowed to dry for a day, and has been checked for cracks, a covering layer of *nill* is applied to the base (Figure 10-8) and the lower surface of the vessel, extending up to the tap (Figure 10-9). The vessel is placed upside down. The additional covering layer serves two purposes. First it serves to strengthen the base and the tap attachment. Second it serves to cover up cracks that may have formed in the base or initial layer of *nill*. Overall the potter may spend two hours working on three pots over the course of two days.



Figure 10-5: Tap attachment in parallel. 3 vessels being prepared for tap attachment in parallel.



Figure 10-6: Tap stabilization. Tap wedged in vessel using another clay vessel and shards for support.



Figure 10-7: Tap attachment. Tap is fixed in place using *nill* on inside and outside of vessel.



Figure 10-8: Base covering. *Nill* is applied to the base forming an outer layer.



Figure 10-9: Extension of base covering. *Nill* layer is extended up to the tap and around the base of the vessel.

10.3.2 Amilo-Rangwe

The Amilo-Rangwe group has the least efficient setup for attaching the tap. Only the manager of the organization where the group is based is trained to attach the taps to the vessels. Even vessels made by potters who work from home, need to be brought to the central workshop to be finished. In addition to the bottleneck that can occur, the attachment process is not always uniform. First water is splashed on the surface where the cement will go. Next the tap is stabilized in the opening using rocks and pot shards to wedge it in place and support the tip of the tap (Figure 10-10). This setup often requires a fair time investment to ensure the tap is properly stabilized before cementing can begin. To prevent cement from clogging the tap during fixing, the end of the PVC tube is stuffed with plastic or cardboard. A cement-sand mixture consisting of 2 parts sand, 1 part cement, and a scoop of water proofing compound is used to fix the tap. Cement is initially

applied to the interior and exterior of the opening (Figure 10-10). The layer of cement compound is then extended to the immediate area surrounding the opening and built up slightly. The cement is then given some time to dry, while more is prepared for the base. The vessel is then positioned upside down, and a layer of cement is extended from the initial mound around the lower walls of the vessel. Finally a layer of cement is applied to the base (Figure 10-12). The additional layer of cement serves to reinforce the vessel and the tap, and fill in any cracks that may have formed.



Figure 10-10: Tap wedged in vessel. Tap is stabilized by rocks and pot shards.



Figure 10-11: Tap attachment. Stabilization tap using cement.



Figure 10-12: Base cement covering.

10.3.3 Kinda E Teko

The Kinda E Teko group has the simplest tap attachment process. Because the opening is only made using the PVC tubing, the opening is usually snug if not too tight. If the opening is too small for the PVC tubing due to shrinkage, the lower half of the vessel can be soaked for half an hour, and the opening enlarged by smoothing. Once the pipe is in the opening it is secure, and can be easily cemented in place. A cement-sand mixture of equal parts is used. Whether this mixture is also technically referred to as *nill* was not clear. The inside and outside of the vessel are first covered. Next the lower vessel is covered with a layer of cement, and then finally the base is covered.

Chapter 11

Quality Assurance

11.1 Quality Assurance Background

In the industrial and commercial settings of modern ceramics, Quality Assurance is a critical component of the production and manufacturing process. Products are designed and built to specifications for particular uses. The fidelity of the production process to those specifications is important if the product is going to be reliable and safe. Quality assurance serves two basic functions: maintaining control over the production process and rejecting faulty products [7].

The amount of resources invested in maintaining quality assurance for a product is directly related to the nature of its application. A simple container may only be inspected to ensure its physical integrity, while precision components may have to meet precise dimensioning standards. Regardless of the complexity of the protocols needed to maintain quality assurance, the production process must first have a written specification. The written specification details in depth the processes that must occur at each and every step of production, and how those processes occur. For example, in selecting raw materials, the specification can dictate the acceptable ranges of specific physical or chemical properties. During shaping, tolerances for dimensions can be enforced, or the range of defects that can or will be tolerated is established [7].

A variety of techniques and methods exist for testing whether a product meets a certain specification. However, only two techniques are generally applicable or needed to

test for the specifications required in traditional ceramics: proof testing, and non-destructive inspection [7].

11.2 Proof Testing

Proof testing consists of testing the product under true environmental conditions. By simulating working conditions the behavior of the product can be observed and analyzed. Proof testing can be used to answer simple questions such as ‘Does the component work as expected?’ or “How does it fail?” Non-destructive inspection is a broad category of techniques that examine the surface or subsurface without effecting or destroying product being tested. Techniques for non-destructive inspection range from visual inspection to ultrasonic detectors to x-ray imaging. The three pottery groups rely entirely on visual inspection to carry out all non-destructive inspections [7].

11.3 Non-destructive Inspection

Non-destructive inspection as a form of quality assurance exists in limited forms but is not recognized as a formal step in the production process. The majority of quality assurance used in the production process is self-imposed by the potter. The potter in the course of shaping the vessel may realize that it will be too big or too small and start over. During firing, if cracking occurs the vessels may be patched up with cement, relegated to dry storage or tossed out depending on the severity of the defect [7].

11.4 Quality Assurance Practices

One of the largest problems indigenous potters have is identifying the source of a defect with respect to material properties. While properties such as texture and preparation time are immediately accessible, slight differences in vessel strength or defect rates are likely to go unnoticed without a systematic procedure for reviewing them [10].

Of the three groups, only the Kinda E Teko group formally carries out quality assurance protocols that extend beyond casual visual inspection. Before the group will allow a vessel to be sold at market proof testing is carried out. The group tests to ensure

the vessel is capable of holding water for a week. For the other two groups, the burden of quality assurance is largely placed on the customers to return the vessels if they prove defective. The groups then exchange the defective vessel for a working one.

11.5 Defects

A number of defects can occur during the production process that renders the vessel unfit to store water. After conducting interviews with the potters and examining the production process, two general classes of defects for the modified clay pot were identified: excessive leaking and reduced vessel strength. The two defects can occur independently, but often share the same causes.

11.5.1 Excessive Leaking

Excessive leaking can be caused by a number of factors ranging from high porosity levels in the ceramic material, to the formation of cracks in the vessel wall, to poor attachment of the tap to the vessel.

11.5.1.1 Porosity

The porosity of the vessel surface may allow a pot to be excessively leaky despite the fact there are no visible cracks (Figure 11-1). The porosity of the ceramic material enables evaporative cooling by allowing water to be drawn away from the vessel surface while absorbing heat. However, only small quantities of water are required to maintain the effect, and excess flow to the vessel surface results in visible leaking and pooling of water at the base. Differences in the porosity of the vessel wall can be observed by examining where moist patches first begin to appear upon filling of the vessel (Figure 11-2) [7].

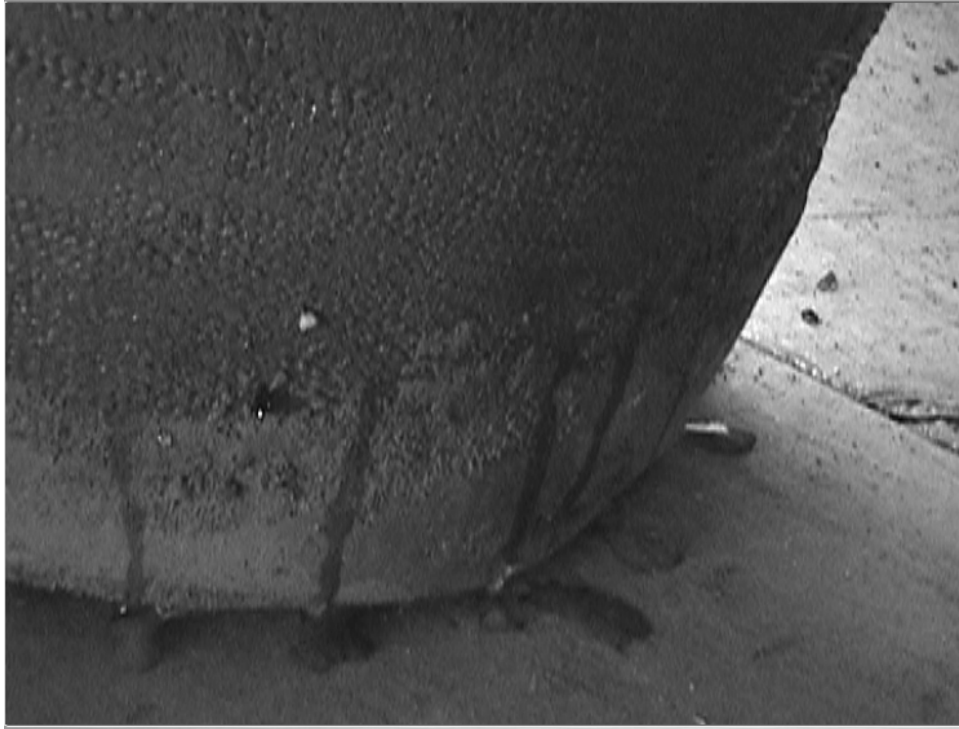


Figure 11-1: Excessive leaking. Due to high material porosity visible streams of water collect along surface and pool at the base.



Figure 11-2: High porosity regions. Dark patches form as water permeates to surface.

11.5.1.2 Cracks

Cracks in the vessel wall can form due to the stresses of drying and firing, or from weak joins in the shaping process. Figure 11-3 shows cracks formed in a vessel after firing at Amilo-Rangwe. The severity of a crack depends on its location, size and depth. The lower a crack is located on the vessel surface, the higher the hydraulic force will be, and the more severe the leaking. Cracks often form in the base of the vessel because of the thickness of the clay (Figure 11-4). Small cracks that do not penetrate the thickness of the vessel can often be patched with cement, if the vessel does not break first. If a small enough crack occurs near the top of vessel, close to or above the level to where water is regularly filled, then it may simply be ignored (Figure 11-5).



Figure 11-3: Firing defects. Cracks formed in vessel after firing at Amilo-Rangwe.



Figure 11-4: Cracked base. Cracks formed in base of vessel during firing, Amilo-Rangwe.



Figure 11-5: Decoration defect. A deep incision during decoration near the top of the vessel, causes excessive leaking, when the vessel is filled to the top.

11.5.1.3 Tap Attachement

Poor stabilization of the tap during attachment can lead to a widening of the cavity around the tap. This widening effectively creates paths for water to short circuit while traveling through the porous vessel wall and cement patch. Short circuiting results in increased flow to the vessel exterior, and more leaking.

11.5.2 Reduced Vessel Strength

Reduced vessel strength can be observed in the vessel surface or the point of tap attachment. Defects such as cracking in the vessel surface may compromise the strength of the vessel and result in breaking, especially when subjected to the stresses associated with being moved while containing water. The tap itself serves as a focal point of stress through ordinary use and its protrusion from the vessel surface. Constant opening and closing of the tap can generate torques that may loosen the tap if it is not properly secured. These forces may exacerbate small cracks that are present, encouraging larger cracks to form until the tap breaks away from the vessel completely. Additionally the tap's protrusion from the vessel surface increases the likelihood that it will be used as a handle or accidentally hit and could result in cracking due to the unintentional application of force.

Chapter 12

Best Practices

Each of the three pottery groups has developed and refined their own production and manufacturing techniques in response to the challenges and problems they have faced. Variations in the production processes between the three groups can range from significant differences in the material inputs to minor changes in the dimensioning of the hole for the tap. These differences in production impact the overall efficiency of the process and quality of the final product. The techniques used by each of the three groups at each stage of production have been examined for their efficiency and their effect on the final product. A list of best practices at each stage of production has been compiled below.

12.1 Gathering

The gathering stage of production is limited by the availability of local clays, and the pottery group's abilities to locate and identify deposits. Given the spatial resolution of the geologic maps available at the time of this writing, it is not clear whether variations in the clays used by the groups is inherent in the local geology or merely the result of the source used by the potter. Of the clays used by the three groups, the clay used by the Kinda E Teko group appears to be the most desirable in terms of the low porosity that is produced. No best practice was identified for the gathering stage of production.

12.2 Processing

The techniques used to process the clay vary, depending on the material properties of the raw clay. In this sense it is difficult to identify one single technique for processing clay that stands out. Instead, the refinement of the processing technique itself is being

highlighted. The Oriang group has identified that the use of fine sand, obtained from rivers, instead of coarse sand, approximately 200 mesh, in tempering results in less leaking through the ceramic surface.

For the processing stage of production, the use of fine sand was identified as a best practice. The sand is naturally available near rivers, where levigation takes place. Additionally, fine sand could be procured using sieves with a higher mesh count.

12.3 Shaping

Shaping methods are similar between the three groups. No best practices for shaping were identified.

12.4 Decoration/Modification

The Oriang group's extensive use of decoration in adorning their modified clay pots highlights the importance of aesthetics in production. While the functionality of the pottery is the most important factor in the application of the modified clay pot, the importance of aesthetics in marketing and sales should not be overlooked. Time and effort invested in decoration may improve consumer interest in the item. The Oriang group's intricate decoration patterns were identified as a best practice in the decoration stage of production.

12.5 Drying

The drying process is subject to the occurrence of a number of defects due to non-uniform loss of moisture. In order to limit and reduce the number of defects introduced into the vessel a controlled environment should be maintained during drying. The Oriang group specifically has a room dedicated to the storage and drying of pottery that limits

environmental factors such as wind and sunlight from disturbing the drying process. While an elaborate structure is not needed for drying, a simple dedicated space that reduced influence from environmental factors should improve the drying process for the Amilo-Rangwe and Kinda E Teko groups.

12.6 Tapping

The tapping process is complicated by the unknown amount of shrinkage that will occur during drying and firing. The Oriang and Amilo-Rangwe groups attempt to compensate for this shrinkage by widening the hold extensively, so that even after firing there is plenty of room. However, this procedure complicates the attachment process. The Kinda E Teko group's method of only tapping to the size of tubing or slightly larger reduced the complexity of subsequent steps, even though after firing, slight smoothing of the opening may need to occur to fit the pipe.

The Kinda E Teko group's method of using the pipe to tap the pottery is a best practice for the tapping stage of production, and can easily be implemented by the other two groups.

12.7 Firing

Only the firing techniques used by the Oriang and Amilo-Rangwe groups were observed. No metrics were established or tested to determine which process might be most effective. However, one significant variation in their fire building was observed. The Amilo-Rangwe places a bed of fuel below the pottery, while the Oriang group only places the fuel on top. Given the extensive amount of heat lost directly to the atmosphere, the Amilo-Rangwe group's practice of placing fuel below the pottery may be more efficient and reduce the amount of fuel needed to complete the firing process. The Amilo-Rangwe group's placement of fuel at the base of the open fire, is a best practice in the firing stage of production, and may lead to lower fuel usage during firing.

12.8 Sealing

The Oriang and Amilo groups apply sealant to the exterior of the vessel, and the Kinda E Teko group applies sealant to the interior. Further tests need to be conducted to determine if one approach is more effective than the other. Therefore, no best practices were identified.

12.9 Tap preparation

In cutting the length of tubing used, the Oriang and Amilo-Rangwe groups use of a measured standard is the most efficient in reducing waste.

In fitting the tap to the tubing, the Kinda E Teko group's method of cutting a notch in the tubing and the press fitting is the most efficient in terms time and of ancillary materials required, eliminating the need for heating and gluing of the plastic.

The Oriang and Amilo-rangwe group's use of standards to measure pipe length is a best practice for minimizing waste, and maintaining consistency between vessels.

12.10 Tap attachment

The Oriang group's multi-stage in parallel approach to tap attachment is the most efficient in terms of quality and time spent by the potter. By preparing multiple taps in parallel, time normally spent waiting for the tap to set can be spent working on the next vessel. Additionally by breaking tap attachment into multiple stages, the work can be checked for defects, and fixed before the entire process has been completed.

12.11 Quality Assurance

The Kinda E Teko group's practice of testing the modified clay pot to make sure it will hold water for extended periods of time is the extent to which quality assurance programs are instituted by the three groups. Though all three groups may apply quality assurance to some limited extent, the Kinda E Teko group is the only one to explicitly incorporate into the production process. The explicit testing of the vessels is a first step to

setting minimal qualitative and quantitative standards for the production process.

Additionally the practice of testing the vessels limits the number of faulty ones that may be sold at market, improving the overall quality of the sold product and increasing customer satisfaction.

Chapter 13

Expansion and Scaling of Production

The production process for the modified clay pot can be scaled up in two ways: increasing production staff, or increasing production efficiency. The three pottery groups represent a continuum of production levels spanning these two options. At one extreme is the Oriang group which has a large number of fully dedicated potters, at least 30, 15 of whom are full time, and a very efficient production process. In the middle is the Amilo-Rangwe group which has a large number of partially dedicated members, over 30, and a moderately efficient production technique. At the other extreme is the Kinda E Teko group, which has a small number of partially dedicated potters, around 6, and a relatively inefficient production process.

13.1 Expansion of group membership

As evidenced by the Amilo-Rangwe group, increased production rates can be achieved by increasing the number of potters. The Amilo-Rangwe group uses a distributed network of potters who produce the bodies for the modified clay pot at home and then bring them to the workshop to be finished. This arrangement is advantageous because it does not require a large central workshop to accommodate production, and because it allows the group to utilize potters who otherwise might not have the time to travel to the workshop. The drawbacks to a distributed production process include less control over production and increased inefficiency. In a distributed production network, control over the production process is retained by the individual. The potters must choose which locally available resources to use, and then they must make all critical decisions during production. Additionally, working outside of the group setting, a potter will not

have standard methods of feedback from her peers to correct and adjust her work. The inefficiency of the process also increases as access to shared resources such as tools are diminished. Additionally, the firing process becomes more inefficient as it is scaled down to small batches consisting of a few vessels. Production can easily be scaled by recruiting a network of semi-independent potters in order to avoid the capital investments associated with centralized production, such as a central building, and communal resources. However, resources still need to be invested in maintaining and supervising the network and its members to ensure standards in the production process and maintain production levels.

13.2 Increase in Efficiency

Increasing the efficiency of the production process allows fewer individuals to produce more. The Oriang group best demonstrates the effects that increased efficiency can have on the production rate through use of specialization, tools, and increased scales of production. Specialization in the production process is primarily found in the tapping, firing, and attachment stages, but could be extended to any stage of production. Instead of each potter seeing each vessel they produce through the entire production process, a few potters are trained in the tap preparation and attachment stages. By specializing, a few potters can attach taps to large batches of vessels in relatively short amounts of time. Specialization in production reduces the amount of time the potter spends transitioning between stages of production, increasing the production rate. Specialization also increases quality and consistency of the work, reducing defects.

The importance of tools to the efficiency of the production process cannot be overstated. The most glaring example is the use of a potter's wheel versus an un-elevated clay disc in section 4.4. The potter's wheel allows the potter to access quickly all sides of the vessel while sitting. In contrast, an un-elevated clay disk requires the potter to assume a variety of positions from crouching, to doubled-over at the waist to interact with the vessel. These un-ergonomic positions limit the amount of time the potter can spend working, and decrease the rate at which she can work.

Many aspects of the production process become more efficient as the scale of production increases. Gathering and processing clay becomes much more efficient as the

batch size increases. Fewer trips need to be made by potters to gather the clay, and less time is invested in waiting for the batches of clay to set and age. The costs associated with firing also decreases, as proportionally less fuel per vessel is needed to fire larger batches of pottery, which reduces the amount of time spent gathering fuel.

Chapter 14

Recommendations

After observing and reviewing the production processes of the Oriang, Amilo-Rangwe, and Kinda E Teko groups I have identified four main areas of the production process where improvement can be readily made using available resources and knowledge. The four areas for improvement were also selected for impact they would have on improving the efficiency of the manufacturing process and the quality of the modified clay pot.

14.1 Developing Clay Resources

As the major material input, the clay dictates the majority of the physical properties of the fired ceramic, ranging from the fired strength to the porosity. While some of the clay properties can be partially compensated for using post-firing treatments such as sealing, identifying a reliable and suitable starting material would alleviate much of the inherent variability in the production process. In interviews with potters from the Oriang group, potters demonstrate understanding of multiple clay types and their intrinsic properties. Additionally, potters demonstrate understanding of how tempering with different quality materials, fine sand versus coarse sand, effects the leakiness, which is to say, the porosity of the pottery. Clay quality can also be improved by mixing a variety of clays as an alternative to tempering. By investing resources to develop a consistent starting clay with the desired properties, there would be increased uniformity among vessels produced by the different potters as well as a decreased incidence of defective pots [10].

14.2 Standardizing Steps in Production

The overall production process is specified in a very general manner. It is clear certain steps need to occur in a particular order, but the details of those steps are not directly specified. The decisions of how to implement a particular process in production are left completely to the discretion of the potter. While such a flexible system may be convenient in some respects, it introduces a considerable amount of variability into the production process, and the decisions are often insular with respect to subsequent stages of production.

14.2.1 Gathering

In the gathering stage of production, a potter may have many different types and mixtures of clays to choose from. In the absence of suitable quantities of a preferred clay, less desirable clays may be mixed in to supplement the total quantity of clay gathered. Depending on the quantities, and types of clays the potter picks, the final properties of the clay stock could vary considerably between production cycles. These variations will affect every stage of production, requiring potters to make adjustments to compensate for the clay properties. Everything from the amount of time needed to process the clay, to the amount of temper required, to the shrinkage during drying and firing will be affected. By standardizing the amounts of clays used, and which mixtures are best suited for the production process, subsequent stages in the production process can be standardized.

14.2.2 Processing

In the processing stage, the potter makes qualitative decisions as to when the clay is ready. Temper is added until the clay no longer sticks, and water is added until the clay reaches a proper consistency. Too much temper can make the clay too weak after firing, while if too little is used the clay may be too plastic to survive the shrinkage during drying and firing without developing defects. By standardizing the quantities of clay, tempers, and water used during processing, variations in shrinkage rates will be reduced, which will help simplify the tapping stage. Drying times will also be more uniform,

allowing entire batches of pottery to be ready sooner for firing. Defects caused during drying and firing should also be reduced.

14.2.3 Shaping

The shaping stage of production is largely constrained by the shape of the vessel design. However, more accurate dimensioning during the shaping process could allow standardized tools and jigs to be developed to simplify the tapping and attachment stages of production, as well the stacking and arrangement of vessels during the firing process.

14.2.4 Decoration & Modification

Standardization of the decoration and modification stage is not required. This stage represents a finishing stage, where previously standardized aspects are enhanced for aesthetic purposes.

14.2.5 Drying

Time for the drying stage of production can vary considerably during the dry and wet seasons of the year. Under drying of pottery will lead to large amounts of shrinkage during firing as water is driven off, and dramatically increase the likelihood of cracks forming. While there are no adverse effects to over drying the pottery, the associated storage and time costs should not be ignored. Standardized drying times should decrease the overall time pottery spends drying or reduce the occurrence of defects due to under-drying.

14.2.6 Tapping

During tapping the potter must first determine when the vessel is ready to be tapped, the location of the hole vertically and horizontally, the size of the hole and even the angle with respect to the surface. Depending on how the potter chooses these variables, the position and location of the tap will change. These changes can complicate

or simplify the subsequent tapping stage. By standardizing the tap position, and size, specialized tools can be developed to simplify the attachment stage.

14.2.7 Firing

During the firing stage the potter must choose the amount of fuel to use to fire fully a batch of pottery. Too little fuel will result in under-fired pottery with reduced strength. Depending on the severity of the under-firing the pottery may need to be re-fired, requiring even more fuel, increasing the cost of production. Too much fuel may result in over firing and uneven heating, creating defects in the vessels. Standardizing the amount of fuel used for a given batch size will help to reduce costs by saving fuel.

14.2.8 Sealing

The sealing stage is highly variable, as the potter attempts to manipulate a very hot piece of ceramic. Standards in sizes and shapes may lend themselves to a tool being developed to support the vessel while its surface is coated with sealant. Additionally, with the current method, the sealant is applied irregularly and unevenly, which could result in zones of leakiness. Standardization of the sealing process may speed up the rate at which vessels can be treated, increasing the amount of sealing the potter can perform while the vessel is still at a high temperature, further reducing the leakiness of the vessel.

14.2.9 Tap Preparation and Attachment

In the tap preparation and attachment stage the potter must decide how much tubing to use and how best to attach the tap. Minor variations in tubing length per vessel, even as small as 1 cm, can result in large quantities of tubing wasted or saved when multiplied through by a couple thousand vessels. The potter must also decide how far to extend the tap from the vessel. The farther the tap is extended the larger the amount of cement and tubing that is needed. By standardizing positioning and tube length the cost of production can be reduced. Additionally standards in tap placement and vessel shape will enable specialized tools to be developed to simplify the process. One example of such a tool was tested while visiting the Amilo-Rangwe group. A cardboard jig made from a

cardboard cylinder was developed to support and stabilize the tap during attachment (Figure 14-1).



Figure 14-1: Stabilization tool. Carboard tube used to stabilize tap during attachment instead of stones and shards.

14.2.10 Quality Assessment

In quality assessment the potter can choose a number of variables to test and examine. While it is feasible to test every possible variable, it is certainly not economical. By instituting a standardized quality assessment program, those steps of production which possess the highest failure rates can be systematically screened.

14.3 Keeping Records

During production, there are many variables that can contribute positively or negatively to the final product. Currently none of the three groups keep records of the details of the production process for each batch of modified clay pots produced. Because

of the length of the production process, potentially on the order of a month, it is difficult for the potter to keep track of what variables in the production process may have contributed to particular characteristics in a given batch of modified clay pots. By keeping simple records, changes in the production process can be correlated to the results in the final product, allowing for the identification of sources for defects and potential innovations. The production process can then be continually refined and improved upon.

14.4 Sharing Information

The three pottery groups work and act as separate entities. The two closest groups, Oriang and Amilo-Rangwe, are approximately 80km apart, while the two farthest groups, Amilo-Rangwe and Kinda E Teko, are nearly 400km apart. The distances between the groups combined with an undeveloped communications infrastructure in the region effectively isolate the three groups from each other and prevent the sharing of ideas. Though members of the Amilo-Rangwe and Kinda E Teko groups were initially trained at Oriang to produce the modified clay pot, the production processes used by the three groups have diverged. Each group has approached and solved problems they encountered in completely different ways. The three groups stand to benefit from sharing techniques they have developed and their experiences in producing the modified clay pot. Furthermore enhanced communication will foster collaboration and potentially speed up the development and refine the production processes.

The distances separating the groups prohibit frequent meetings between large groups. But, if annual or semi-annual workshops with the groups can be held so large groups of the potters can meet to exchange ideas, and review the production processes this should effectively eliminate any barriers to information exchange that may exist.

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