Ball Clays

NTRODUCTION Ball clays are kaolinitic sedimentary clays that are an important component in most ceramic bodies because they confer strength and plasticity. Most ball clays impart a light cream to white fired color in an oxidizing atmosphere. Ball clays have varying proportions of kaolinite, illitic mica, or sericite and fine quartz, with small amounts of organic matter and other minerals such as smectite. They are commercially valued because they increase the workability and strength of ceramic bodies. Contaminant minerals frequently include pyrite, siderite, iron and titanium oxides, gypsum, and dolomite. The quantity, form, and type of contaminant can influence the usefulness, processing route, and ceramic application of the clay. The major differences between the kaolinite in ball clay and in china clay (kaolin) are particle size and the degree of ordering within the crystal structure. Whereas the kaolinite in china clay is moderate coarse and generally well ordered, kaolinite in ball clay normally has a very fine particle size and is predominantly b-axis disordered. The term ball clay is thought to be derived from the old method of working the clay. The clay was cut into cubes about 9 in. (230 mm) square, each weighing 30–40 lb (13–18 kg); because of the plastic nature of the clay, these rapidly assumed a spherical shape during handling. Clay was sold in this form by the “ball.” Alternatively the name may have derived from a digging implement called a “tubal,” which is still used to mine ball clay in some parts of the world

Processing Raw ball clay is processed into four different forms: shredded, mechanically dried, air-floated (powdered), and slurry. Shredded ball clay undergoes the least amount of processing. In this process, raw clay is run through a shredder , and the resulting product is no more than 2 in. (5 cm) in diameter with a moisture content of about 17%. Mechanically dried clay also has a diameter of no more than 2 in. (5 cm), but it has a moisture value of about 10%. In 2002, shredded and mechanically dried forms represented about 31% of the market and had an average value of $34/t. Air-floated clay is powdered and has a moisture percentage of no more than 3%. In 2002, air-floated clay represented about 40% of the market and had an average value of $54/t. Slurried clay is shipped in liquid form and consists of about 60% clay and 40% water. Slurried clay represented about 29% of the market and had an average value of about $43/t in 2002 (Virta 2004). Reserves of ball clay in the United States at current consumption rates will last far more than 150 years

Geology Overview The sedimentary environments into which ball clays were deposited appear to vary greatly. As a result, the physical characteristics of ball clays vary greatly. In Tennessee, many deposits are narrow and curved; in cross section, they appear to be river channel shaped (Figure 4). These deposits are typically surrounded on the sides and undersides by cross-bedded sands and occasionally fine gravels. Clay deposits of this type generally are dark brown and have tan clay on both the top and the bottom of the deposits (Figure 5)

Occurrence and Origins

By far, most of the ball clay produced in the United States is shipped from the Kentucky–Tennessee region (Henry, Weakley, and Carroll counties in Tennessee; Graves County in

Kentucky). Significant amounts of clay are also shipped from Panola County in Mississippi and from Cherokee County in Texas. The Tennessee, Kentucky, and Mississippi deposits are all located in the Middle Eocene Claiborne Group (Ackerman 1996), which is near the edges of the Mississippi Embayment

The environment in which these clays were deposited is generally considered to be on a fairly flat plain traversed by low gradient, aggrading streams that occupied broad, flat valleys. Seasonal flooding caused major channels to shift paths, leaving behind abandoned, low-energy environments known as “ox bows.” These abandoned channels or oxbows became ideal low-energy environments for the deposition of fine-grained clays. It is conceivable that the larger deposits not confined to a channel are large-scale overbank deposits. Two theories exist for the origins of U.S. ball clay sediments. The first is that Porters Creek Clay in the Middle Paleocene weathered to kaolinite and was transported a relatively short distance to its current locations (Hughes, Moore, and Reynolds 1993). The second is that the deposition of these sediments was the result of the Appalachian River system entering the Mississippi Embayment in Kentucky and meandering back and for the across this wide plain (Potter and Dilcher 1980). Both theories are worthy of more thought and further study.

Mineralogy and Properties

The two major components of ball clay are kaolinite and quartz. Many of the properties important to end users are tied to the relative percentages of these two minerals. The variations in composition can be quite large. In five profiles sampled from working clay pits by McCuistion (1995), the quartz contents ranged from 21% to 64 % and the kaolinite contents ranged from 33% to 80 %. Hughes, Moore, and Reynolds (1993) confirmed that much of the kaolinite present in these clays is mixed-layered kaolinite–smectite. Well-ordered kaolinite represents 37%–67% of the kaolinite within these clays. The kaolinite–smectite component has approximately 88%–99% kaolinite layers (McCuistion 1995). Hughes, Moore, and Reynolds (1993) examined many different deposits and stated that the kaolinite–smectite in ball clay had >80% kaolinitic layers. The presence of this poorly crystallized kaolinite contributes to the plasticity for which ball clay is so well known. Trace clay minerals present in ball clays include illite, smectite (discrete), chlorite, and other mixed-layer clay species. Other trace minerals are mica, pyrite, ilmenite, magnetite, tourmaline, and zircon (McCuistion 1995). The physical properties of ball clay are as varied as their mineralogies, and the variations significantly affect the end uses of the ball clay. Ball clays have the following properties:

- Moisture content between 18% and 22%

- White, various shades of gray and brown, black, tan, pink, and all shades in between

Particle sizes between 15% 3%

- Sulfur content from 10ppm to 7000pmm

- Residues on +200-mesh screens from a trace to 30%

- Deflocculation demands from very low to very high

- Fired color can be white, peach, or pink

- SiO2 from 50% to 70% • Al2O3 from 18% to 35%

- Average Fe2O3 close to 1%

Technology Exploration

Exploration involves planning, drilling, laboratory testing, and geologic interpretation. Ball clay de posits were originally located by finding outcrops that were visible in topographic lows such as ditches and stream bottoms. Although that method is still useful today, most deposits are generally found well below the elevations of even the most deeply incising streams. Drilling has been conducted in the Tennessee, Kentucky, Texas, and Mississippi regions for more than 75 years. Numerous ball clay deposits have been identified and located but not yet developed. In most of these deposits, the locations, depths, and thicknesses are known, but the only quality information recorded was what the drillers logged in the field (color, sandiness, etc.). Because of the extensive drilling done over the past 7 5 year s, modern planning for exploration involves extensive review of historical records to find tracts of drilled land. Tracts of land that have never been drilled are chosen by proximity to known ball clay deposits and location within the general area in which the Claiborne or Wilcox formations outcrop or subcrop. Ball clay deposits in the United States are now located using truck-mounted core or split-tube sample d rills. These drills can recover nearly 100% of the clay encountered. Sampling is typically at 2.5-ft (0.8-m) intervals. Cores are generally 2 in. (5 cm) in diameter. Figure 7 shows a typical rig. Laboratory testing is performed at 2.5-ft (0.8-m) intervals. If an obvious change such as a variation in the color or sandiness of the clay is apparent within that interval, then the sampling interval may be further reduced. Exploration drilling is done with 150-ft (46-m) sp acing between holes. It is necessary to drill this close because some of the deposits may not be much wider across, and drilling at wider spacings could miss some smaller deposits. In most deposits, this distance between holes is sufficient to assess the quality and quantity of the ball clay before removing the overburden. In some smaller deposits and close to the edge of deposits, holes are spaced closer together to ensure quality and to minimize the amount of overburden removal. These holes are then surveyed using either laser - ranging transits or global posit joining system (GPS) receivers. Aerial photography is widely used to assist in both exploration and mine planning. This enables sufficiently accurate contouring to be generated to assess both the overburden and reserves in e ach deposit. Exploration holes are typically drilled to between 75 ft and 100 ft (23 m and 30 m).

Each sample representing 2.5 ft (0.8 m) or less is tested for the following properties:

- Particle size (mainly

Most mapping and modeling is now done with computer-aided design (CAD)-based computer programs. If a deposit has sufficient quality, quantity, and overburden ratio to justify development as a mine, then a three-dimensional property map is produced that displays the surface topography and drill-hole locations. After laboratory testing on the exploration samples, a geologist correlates each layer within a deposit between drill holes. Once the property map is produced, then the drill-hole information is entered into the computer to genera tea three-dimensional model of the deposit. This model generates geologic tools such as cross sections and isopach maps (Figure 4) to aid in the mine-planning process. Just as important, volumes of individual layers can be calculated for both long and short-term planning. Volumes of ball clay are transformed into weights by the following relationship

Mining

Mining involves planning, permitting, overburden stripping, production drilling, actual mining, regular mine sampling, clay aging, and blending. Mine planning requires the joint involvement of various disciplines. Quality, environmental concerns, and costs are all equally weighted in designing a mine plan to balance all three factors. Mine plans are constructed using the same maps generated by the CAD based computer programs. State environmental organizations issue permits. The main federal regulating authority for mine safety is the Mine Safety and Health Administration (MSHA). Open-pit mining, the method used in all U.S. ball clay mines, requires overburden stripping. The dominant equipment used to remove overburden material is self-loading scrapers or tractors pulling self-loading pans (Figure 8). In particularly wet or soft material, it is sometimes necessary to top-load these pans or scrapers with attract hoe. Production drilling is done after the overburden has been removed and before mining takes place. Production holes are spaced 50 ft (15 m) apart to refine mine plans and reserve estimates. The test procedures used in exploration are again used on these production samples. After laboratory testing, the three-dimensional models are updated to make mine plans, cross sections, isopach maps, and estimates of reserves more accurate.

In the United States, the most common equipment used to mine ball clays is the track hoe (Figure 9). The horizontal and vertical variability inherent in ball clay deposits demands precise mining. Some deposits contain six or more different strata. Each must be mined precisely and stored separately for later blending. The clay is loaded directly onto trucks where it is then transported directly to sheds or intermediate storage areas. Once in the sheds, bulldozers push each load of clay onto its appropriate pile. Mine samples are taken on a regular basis at the stockpile in the shed. Testing is done to confirm that all steps up through transport of the clay have been performed correctly. If the samples show clay to be out of specification, the clay is either isolated and used appropriately or moved to its proper stockpile. Mine sample data are also used to make precise blends of different clays to achieve a required combination of properties. Proper aging is important to the deflocculation characteristics of ball clay. Newly mined clays are almost always very difficult to deflocculate. Oxidation and bacterial attack on the mined clay change and degrade the organic matter over time. Sulfate growth is also a result of the aging process and has a profound effect on ceramic bodies. Another benefit of aging is drying; natural drying, in particular, significantly decreases costs. Blending is a major step in the quality control process. Blending clay reduces variations in products by dampening the natural variation inherent in each strata. Blending also allows adjustment of relative percentages to account for changes in the mine. Blending enables adjustments to be made to control trends or sudden changes in a product that are caused by variations in the clay composition or physical properties. Blending also can create “engineered” products not found in the natural environment as individual strata. The ball clays are blended in several different ways. Initial blending is done on the floor before loading into the hopper. With this method, the loader operator is given a recipe for the number of buckets of each clay to mix together. With the second method, the recipe is for the number of pounds of each clay to load directly into the hopper. Scales on the hopper guide the operator in this process.

Preprocessing quality control can be summarized in three major steps: drill sampling (premining) , mine sampling (postmining), and blending. Figure 10 is a flow chart of this process.

Processing

Ball clay in the United States is processed in dry forms and wet forms (slurry). The flow chart in Figure 10 ends by branching to one of these two processes.

Dry Processing Figure 11 illustrates the dry-processing technology pathway. Once a blend is batched and mixed together, a front-end loader deposits the blended clay into a hopper leading to a J.C. Steele feeder. The clay exiting this feeder is no larger than a softball. The clay is then carried up a belt to a crusher that further reduces the size of the clay pieces to 1 in. (2.5 cm) or less in diameter. From the crusher, the clay runs through a dryer that reduces the moisture content of the clay from approximately 20% to about 12%. For mechanically dried product, the clay can be run into a stockpile or loaded directly into a railcar or truck. For air-floated product, the clay is diverted into a mill hopper that feeds clay into a mill that grinds the clay into a powder and dries it further to 3% or less moisture. From the mill, the powdered clay is pneumatically pumped into a hopper. From the hopper, the clay can either be bagged in 50-lb (22.5 kg) bags or pumped into a silo. Trucks and railcars can be loaded directly from these silos or clay can be loaded into 1-tsupersacks.

Wet Processing

The other branch of the flow chart in Figure 10 leads to wet processing, which is further illustrated in Figure 12. Instead of blending clay on the floor as is done with dry processing, individual clays are loaded into the hopper by weight. A digital readout on the hopper shows the loader operator how many tons of each clay have been loaded. When the batch is completed, the J.C. Steele feeder feeds the clay onto a belt in softball-size or smaller lumps and into a crusher that crushes the clay into lumps 1-in. (2.5 cm) or less in diameter. The clay is then fed into ablunger and mixed with water and chemicals. Large blades blend the clay–water–chemical mixture until all the clay has broken down. When blunging is complete, the slurry is then pumped over coarse screens that scalp off the coarser material such as lignite and coarse sand. The slurry is pumped over fine screens that take out even more undesired material. After screening, the slurry is pumped into blend tanks. These blend tanks are checked for quality and consistency and, if necessary, are mixed with other tanks to improve the quality. From the blend tanks, the slurry is pumped in to ship out tanks where the slurry is checked for consistency a final time before the tanks are loaded into either trucks or railcars.