The Art of Ceramics
*The Blend of Art and Science in Technology*
N. Claussen (Editor)



# CERAMIC MANUFACTURING: A BLEND OF ART AND SCIENCE

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*Using a broad definition of art, ceramic manufacturing is discussed from the point of view that a person skilled in the art is still essential for most ceramic manufacturing processes. These people can operate a ceramic manufacturing process or guide process development or scale up based on intuition developed through years of experience in areas where known science has not yet been applied. Slip casting and tape casting are discussed as examples of ceramic manufacturing processes that are still a blend of art and science. Critical questions are raised concerning the future role of art in ceramic manufacturing.*

Ceramic technology is a very ancient art. The ceramic exhibition at the Shanghai Museum dates back several thousand years. The terra-cotta army of Qin Shihuang, the first emperor of a unified China, which was discovered near Xian in 1974, dates back to 220 B.C. and is considered by many to be the eighth wonder of the world. Professor Kingery, in his landmark book, *Introduction to Ceramics*[1], defined ceramics as "the art and science of making and using solid articles which have as their essential component, and are composed in large part of, inorganic, non metallic materials." The use of art and science in 1960 clearly indicates that ceramic technology at that time was a blend of art and science.

Art is defined as "human ability to make things." The Indo-European base of art is ar, which means to join or fit together. In keeping with the broad definition of art that is being used for this forum, this paper focuses on art as the skill to make a ceramic manufacturing process work through intuition. That is, a person's ability to perceive how to make a process work without conscious reasoning. Today most ceramic manufacturing processes still require a significant amount of art, even though ceramic science has made major progress in the last 40 years, and scientific principles now form the foundation for most ceramic manufacturing processes.

Engineering is defined as the "science concerned with putting scientific knowledge to practical use." However, I believe a more appropriate definition should include the application of engineering experience, technology, and art as well as science, at least for the successful ceramic engineer and more generally for materials engineers. Although few ceramic manufacturing processes can be designed from first principles, the use of sound engineering principles to apply the known scientific principles that apply to a particular manufacturing process can go a long way toward developing, scaling up and operating a successful ceramic manufacturing process. However, still today, without a knowledge of the art in a ceramic manufacturing process, the road to a successful manufacturing process can be very long.

One example is loading a mixed set of parts in a kiln. When someone who knows the art does it, good parts are produced. When someone who is not skilled in the art does it, the parts will likely come out warped or cracked. If you ask the person skilled in the art how he decides the setting scheme, he can not really explain it. That is what makes it an art. His decision making takes into account several factors and arrives at decisions that are still too complex to calculate. He probably can not even tell someone else what those factors are nor how he arrived at his decisions. He has just learned this art through trial and error over time. Most ceramic manufacturing processes still require some art like this to make them work effectively. Two ceramic manufacturing processes that illustrate this blend of art and science are slip casting and tape casting.

## SLIP CASTING

Slip casting is a very ancient ceramic forming technique, dating back to the Egyptians prior to 100 B.C. Like other early ceramic forming techniques, slip casting started as an art, and science has gradually replaced some of the art. The science of slip casting began in the early twentieth century with the discovery of deflocculants which allowed complex shapes to be formed. In 1980 Cypress Industrial Minerals Company published a book by G.W. Phelps, S.G. Maguire, W.J. Kelly and R.K. Wood.[2] To my knowledge, this book was the first and is still the only comprehensive treatise on slip casting. Unfortunately, it was a limited edition that was not published in the open press. However, it did an excellent job of describing the state of the science of slip casting at that time. Even though the science of slip casting has developed significantly since 1980, there is still a high degree of art in commercial manufacture of ceramics by slip casting.

In 1978, a Rutgers ceramic engineering student took a summer internship at a sanitaryware plant. His first day on the job, he was given the task of producing a single acceptable toilet bowl casting in one week on an eight-position casting bench. He had worked on slip casting as an undergraduate technician for Rod Phelps for two years and thought he knew everything about slip casting. In spite of his training, he was unable to produce even a single acceptable toilet bowl by the end of his one week assignment. Why did he fail? He knew a lot about the science of slip casting but little about the art. Perhaps this experience is what taught him to have a high respect for those skilled in the art of slip casting, as well as all other skilled factory workers. Perhaps it also formed the basis for Professor Haber's strong motivation to further develop the science of slip casting as well as to further understand the art of slip casting.

Recently, I spoke to a person at a sanitaryware manufacturer about how they train casters. Their procedure is to hire people who have already mastered another craft such as carpentry, plumbing, or even automobile mechanics. Then they put them through a two week school, followed by two years of apprenticeship. Only then are they given responsibility for a casting bench. They usually improve their performance in terms of acceptance rate and number of pieces cast per day over several more years as they gradually become more skilled in the art of slip casting.

What is the art in slip casting? It is the ability developed, through years of experience, to take into account the several factors that influence slip casting in an intuitive way. Some of these factors are:

Slip properties
Mold condition
Casting time
Demolding point
Drying

Slip rheology is perhaps the most important variable, and slip preparation is normally not under the control of the caster. However, the caster may make minor additions to the slip to adjust rheology. More importantly, the caster must adjust other parameters such as mold condition, casting time and time to demold to account for variations in slip rheology. Slip properties depend on many factors including: time-dependent rheology, degree of deflocculation, solids loading, particle size distribution, soluble ion concentration (sulfate, calcium, sodium, etc.) and temperature.

Mold condition is also an important variable that the caster must take into account. Gypsum molds are difficult to produce with consistency, but more importantly their behavior changes over their life. Gypsum has some solubility in water, so the microstructure of a mold continuously changes with time toward a larger pore size distribution. Furthermore, slip deflocculants have a tendency to gradually change the mold surface. The net effect is that casting rate decreases with mold age, and the caster must take this into account in his decision-making process. The water content of a mold must also be taken into account, since it affects casting rate, mold recycling time and sticking. If the mold is too high in water content, casting rate suffers. However, this must be weighed against the increased drying time to further reduce water content. If the mold is too dry, the part is more likely to stick to the mold. The slip always contains particles smaller than the largest pores in the mold surface. It is now known that the soluble sulfate in the pore water at the mold surface causes the first cast layer to flocculate so the casting does not penetrate into the pores on the mold surface. This also explains why materials other than gypsum that have the same pore size distribution can not be used successfully for casting, unless they have some water containing sulfate ions placed on their surface prior to casting or some external means is used to separate the cast from the mold, i.e. air or water pressure. The caster must take all of these and many more factors into account in his intuitive, non-quantitative decision-making process to produce quality ware at high rates.

Drying of cast ware is also a blend of art and science. From a science standpoint we understand the effects of temperature, humidity and air flow rate as well as the importance of the permeability of the body, the viscosity of the pore water, and the shrinkage stresses below the critical point of drying. From an art standpoint, we know how to adjust permeability of the body through selection of clays to reduce drying stresses. Persons skilled in the art also know how to stack ware in driers to obtain more uniform drying. In extreme cases, the skilled person also knows how to use "bandaids" like painting glycerin on the surface to achieve uniform shrinkage rates of thick and thin sections.

Today the scientific understanding of slip casting is far advanced over what it was when Rod Phelps *et al* wrote their book entitled *Rheology and the Rheometry of Clay-Water Systems*[2]. Our knowledge of the physical properties and crystal chemistry of clays is much better as is our understanding of their surface and colloid chemistries. Our understanding of the rheology of slips and castings has also been greatly improved through advances in rheometry instrumentation, as has our ability to measure particle size and analyze chemistry. And like most other areas, developments in computation capability have greatly enhanced our ability to better quantify slip-casting science. However, our best science and our best engineering practice has still not been able to eliminate the need for someone skilled in the art of slip casting to produce quality ware at a high rate. Even for newer processes like pressure casting and gel casting, where the art is still being learned, a person skilled in the art is still an invaluable member of the development and manufacturing teams.

## TAPE CASTING

Tape casting, like most inventions, was developed to fill a need. The need for thin capacitors to replace mica in the early 1940's was what led to the development of tape casting. The first step in the development was made by Glenn Howatt.[3] He used a knife to spread a slip on plaster bats. Like many