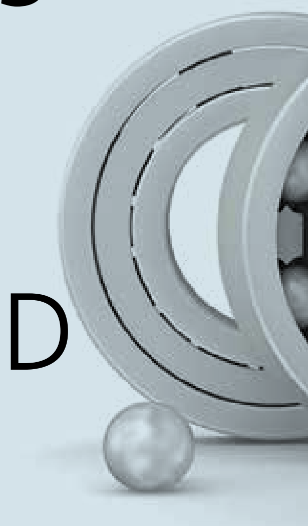
SHARING KNOWLEDGE **ACROSS THE CERAMICS** SECTORS—REDUCING **BATCH-TO-BATCH** VARIATION IN ADVANCED **CERAMICS USING** PROCESS CONTROL



By Andrew Perry

As ceramic processes leader at Lucideon, I'm in the privileged position of working with a wide range of clients who manufacture and process many different types of ceramics, covering all of the different ceramic sectors from technical ceramics through to building products and whitewares. Although the sectors are very different in terms of the products they produce, the issues they face are often similar with variation in product performance, processing, and yield issues being the key areas of concern.

While many of these sectors have little communication with each other, the Lucideon team, specialists in specific areas who come together to work as one to tackle a client's problems, has in-depth knowledge of challenges across all sectors. What is apparent to us is the very different approaches to processing in the different sectors and how cross-fertilization of knowledge across sectors could help to solve challenges. Simply put, what can they learn from each to improve their processing?

In this article, I'll look at where problems can occur with processing and how the technical ceramics industry might take up lessons learned in the more traditional, clay-based sectors to reduce those problems.

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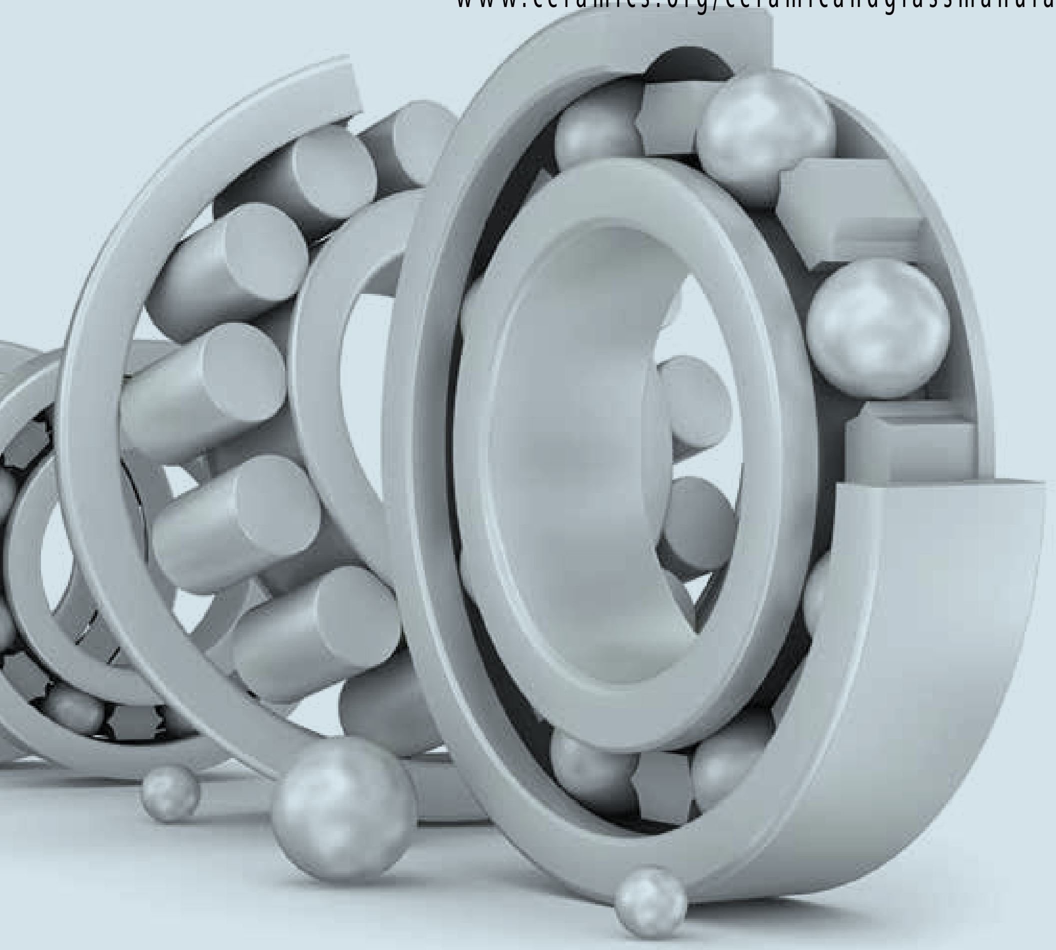
PRINCIPAL SOURCES OF VARIATION

For all production processes, the classic areas where problems can be introduced are man, material, machine, and process. Slight variations in each of these areas, and in the combination of these areas, can have a profound effect.

Man

People influence many areas in the process, including the design of the process itself, and the many process controls that are implemented. Starting at the beginning of the process, the operator needs to select the correct raw material and weigh the required quantity of each material to produce a batch, an area where we often see potential for error. Many advanced ceramic manufacturers produce items of relatively small dimension, therefore a "batch of material" may be a couple hundred kilos at the most. Compare this to other areas of ceramics manufacture where batch sizes of several tons are more typical, which



in turn have prompted greater use of automation. The direct effect of an operator weighing out the material, has a number of aspects:

- Correct material,
- Correct material quantity,
- Housekeeping/contamination between materials,
- Following the correct use of instrumentation,
- Testing regime and procedure.

Each one of these areas has the potential to introduce variation irrespective of the final product type.

Process

Process variation covers a huge potential area, for any part of the process that can be adjusted, intentionally or unintentionally, has the potential to cause variation. For example, a spray dryer can be adjusted by various parameters, or the speed at which the product moves through the process can be adjusted—both these would have a dramatic effect on final product performance.

These variables are often used by the many process improvement tools such as Six Sigma, lean manufacturing, and demand flow technology, all of which are excellent tools to benchmark and map the key process variables and the associated throughput by area. In the clay-based ceramic sectors, process design will often require quality control checking at various stages, something that is usually not seen as required when designing a process to produce a technical ceramic.

Material

Raw material type is normally what differs in processing routes and methodology across the ceramics manufacturers, and hence is normally the driver for the different approaches to material control. The term 'raw material' is also used in different ways, depending on how much material processing is performed by each client. For example, one site may purchase a blended suspension or even a dust/granulate, which is called the raw material by that site, whereas another may take individual materials that require further processing and storage, blending them into a slurry or paste with a range of additives and organics. Each component here may be termed the raw material. It is therefore important to understand what is defined by the term raw material.

Batch to batch variation of a single material or blend gives rise to investigations in the following areas:

- Particle size,
- Chemistry,
- Rheological properties,
- Firing characteristics,
- Forming variables.

At this stage, the material specification, and the associated tolerance during further processing, becomes the focal point. It is very common for both nonclay and clay-based manufacturers to find that the mate-

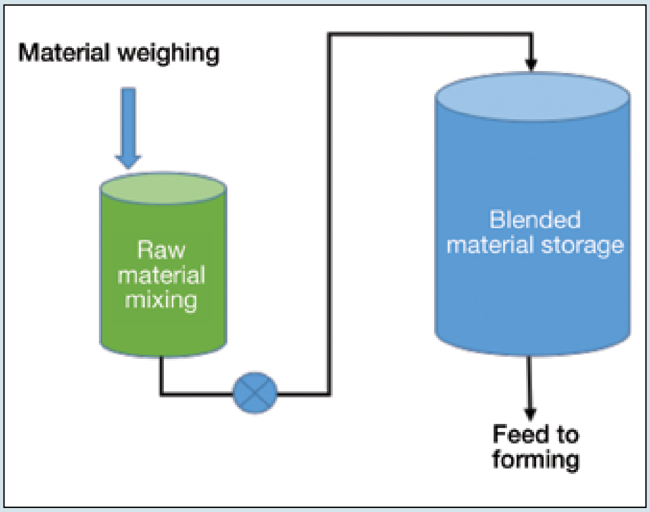


Figure 1. Schematic of typical material preparation for an advanced ceramic suspension.

rial is "within specification" and yet different enough from the last batch to cause problems in a process. This issue is normally because one particular aspect of the raw material is key to a given process and has less tolerance in a specific area than the raw material manufacturer provides. This point may lead to the raw material supplier being able to adjust or blend products for the manufacturer, provided the

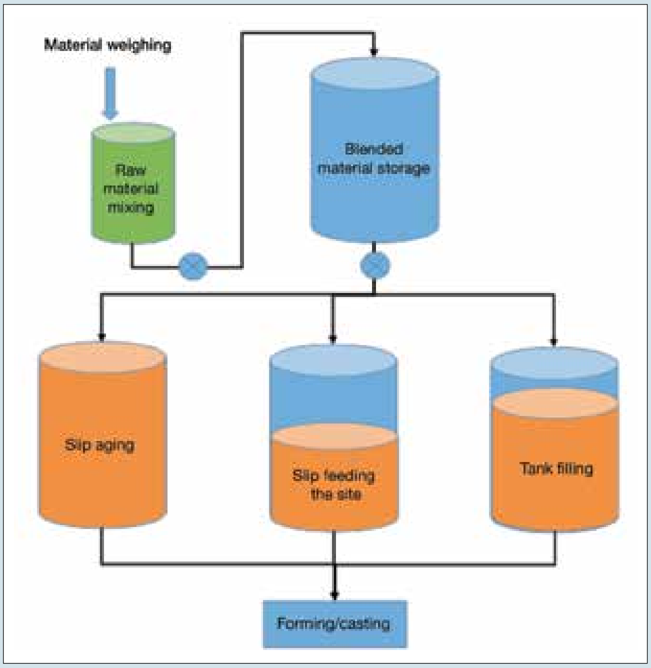


Figure 2. Schematic of typical three-tank slip storage system often utilized within clay-based production systems.

economies of scale make sense, a distinct disadvantage when very low volumes are being consumed, as in the case of the production of technical ceramics.

Raw material specification is normally a function of the level of processing a material undergoes. Materials for technical ceramics may have tighter specifications and higher purity requirements than the clay-based side of the industry. The added complication of particle shape and organics within the clay side of the industry then leads to different approaches to the processing of the required raw materials in the production of a blend.

THE PRODUCTION OF A CERAMIC SLURRY, COMPARISON BETWEEN TECHNICAL AND CLAY-BASED CERAMICS

Figure 1 shows a typical processing route for an advanced ceramic suspension or slip. In this technical ceramics example, the recipe of the blend will include any surfactants and required binders as functions of the dry weight of the primary materials. Here, the purity of all the materials is critical. The materials are blended in the mixer for a given time before being fed to the associated storage tank, often held overnight under constant agitation before being formed.

A similar system is used within the clay-based side of the industry, with additional storage facilities. Larger batch sizes also dominate, which correlates to the daily usage of each material type.

Figure 2 shows an example of the classic way in which clay-based ceramic systems ensure that the rheology of the final slurry is under tight control. The blend is produced in the same manner as with technical ceramics; however, the deflocculants/surfactants are treated as super-additions, such that the addition level can vary. The three-tank rotating system utilizes a feed tank that supplies the site, an aging tank, and a tank that is being filled. The rheology of the slip feeding the "filling" tank has been adjusted to the required target values, the rheology of the slip in the aging tank is monitored and adjusted if required, and the rheology of the feed tank to the process is recorded.

The key reason for the difference between the systems is the state of deflocculation of each ceramic system. Technical ceramics tend to operate with the maximum surfactant level controlling the final viscosity as a function of the solids loading.

Figure 3 shows the deflocculation curve for both clay-based and technical ceramics, plus the typical operating region used to produce the best results during forming.

The graph (Figure 3) shows that the clay-based systems do not typically operate at full deflocculation, and therefore require both measurement and control systems to ensure they are in the correct region of the curve. These differences have also led to a range of different rheology control systems, with technical ceramics being far closer to Newtonian than clay-based. Often, a single viscosity point will be measured at a relatively high shear rate, for example, using a Brookfield viscometer with spindle number 2 or 3, at 70 rpm to record a single viscosity. Clay-based measurement systems will consider the change in viscosity with time, and a range of different measurement systems are utilized, often performed at lower shear rates to allow the material to gel without the measurement device destroying the gel during testing.

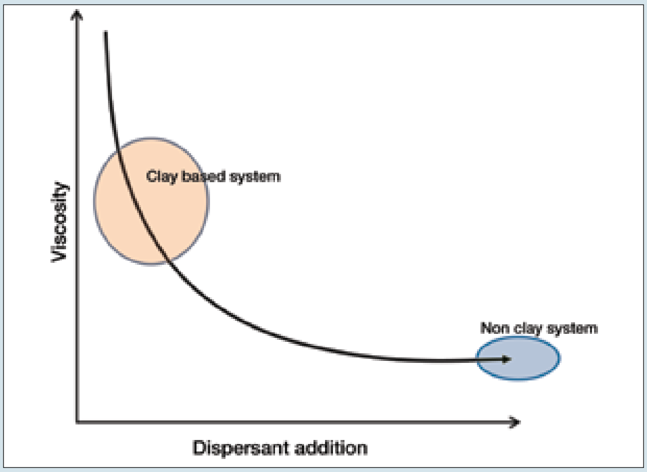


Figure 3. Deflocculation curve representation, showing the deflocculation level utilized for clay and non-clay slip in relation to the viscosity of the associated suspension.

WHERE DOES THIS COMPARISON TAKE US—KEY LESSONS

As with any other industry, process steps and controls are only in place because they have to be. Variation within an individual process is also built into the tolerance of the whole process. For example, a firing curve is normally longer than it needs to be, as is drying, which increases cost and timescales. It is often the interaction between process variations that ultimately leads to production issues. For example, an individual process may be within the agreed tolerance of the measurement system employed, however, that measurement system might not be delivering all the required information to ensure the material is suitable for the whole process. If it isn't, what correction steps are in place?

Six Sigma teaches the importance of measuring the measurement system, via Gauge R&R (reliability and repeatability) and the importance of data itself, especially within the analysis of multivariable systems. The effect of variation from the three key sources—man, process, and material, needs to be quantified with regard to the effect on a given process and its output. To understand this variation, it must be measured, and measured in a repeatable fashion.

In the example of suspension preparation discussed here, the clay side of the industry performs a large amount of rheology testing, and often adjustments associated with each measurement could be argued are a result of variation within the incoming materials, and the fact that the point of deflocculation is critical. On the technical ceramics side of the industry, though, the nature of the materials used and the deflocculation state mean that less variation will occur. While the effects of material variation are therefore rare, there are still man and process variations with which to contend. The lack of relevant testing after each process is often the primary cause of faulty parts. If tests were carried out, information could be used as part of a multi-vary analysis to better understand the most important variables in the system.

The effect of variation on the final product from each source must be evaluated to drive the required process controls, and to determine the key process requirements and capability of each process step. The best-performing sites within the clay side of the industry perform a series of tests after each process step—because they have to. While traditional ceramics manufacturers still have a lot to learn with regard to the correct testing regimes and interpretation of the associated data, in order to optimize processing times and yield, the technical side of the industry could learn a lot from them. Rather than relying on material purity and consistency, more selective and relevant testing could help them to understand the interaction of variation from each stage through the process, and each input variable.

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