Ceramic Processing Using Microwave Assist Technology

Innovative technology offers significant potential for ceramics manufacturers.

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Top photo: Fig. 2 MAT batch production inert atmosphere electric kiln with a working volume of 30 ft^3 used to fire ceramic products by Ceralink.

In today's competitive market, manufacturing efficiency and innovation are a must. Profitability in the ceramic industry will depend more and more on the use of technologies that increase efficiency or enable new products. It is critical to evaluate the manufacturing process and determine the most costly steps and bottlenecks.

Tremendous advances have been made in the past 30 years because of improvements in raw materials. Handling and consolidation techniques also have improved, but the firing cycle is still a serious bottleneck for most ceramic manufacturers. Of increasing concern is the rising energy costs and carbon footprint associated with the ceramic firing process. These factors are leading to the uptake of microwave assist technology (MAT), which cuts the firing time and energy consumption in half.

MAT is a patented method of combining microwaves with conventional heat (gas or electric) so that products are heated internally through dielectric frictional processes, while the surface is prevented from cooling with conventional radiant heat. A small amount of microwave energy is used to decrease the total energy consumption, usually by 50% (Fig. 1). The microwaves target the product, while the conventional kiln acts as a balance to maintain uniformity. The kiln does not have to work as hard, because the product is heated internally with microwaves. The microwave energy goes directly into the parts and is not wasted in the kiln furniture, furnace insulation and other nonproduct materials.

MAT is easily scalable (Fig. 2) and has been tested on many ceramic materials. An international consortium of ceramic manufacturers tested their products in MAT batch and MAT tunnel production kilns in the United Kingdom in the late 1990s. Products tested included advanced ceramics, brick, clay, high-alumina brick, sanitary ware, tableware, tile, abrasives, pigments and refractories. Almost all products could be produced at twice the speed with equivalent or better quality. Cost benefit analyses were performed for several products, and the payback period was shown to be less than three years. An updated cost benefit analysis was performed for a brick company in 2006, which showed a payback of 13 months, partly because of an increase in gas prices. The design of MAT kilns also has advanced, leading to decreased kiln costs.

MAT is licensed exclusively to Ceralink Inc. in North America, Carbolite in Europe and nonexclusively in Japan. In addition to selling MAT kilns, Ceralink has been performing extensive research on MAT processing of materials for U.S. manufacturers. Attracted by the significant energy savings, the New York State Energy Research and Develop-ment Authority (NYSERDA) has invested in Ceralink's MAT projects. These projects are targeted toward helping New York state manufacturers implement efficient technologies.

Manufacturers Discover Benefits

Blasch Precision Ceramics is a manufacturer in Albany, N.Y. The company produces a wide range of ceramic products for use in metallurgical, petrochemical, heat-treating, glass, power generation and chemical industries. One specific product example is a SiC/Al_2O_3 sleeve, which is used in the power generation industry. In this application, the part sees erosion from coal particulate and fly ash. The SiC sleeve has extended the life of this part, compared with the metal sleeves used in the past and has helped to lower the overall operating costs.

The Blasch process is a unique, proprietary forming method developed to produce net-shape and near-net-shape ceramic parts exhibiting attractive physical properties. The process allows for the precise control of dimensional tolerances and the manufacture of complex shapes with no need for machining. Parts produced through this process have excellent resistance to infiltration because of microporosity, with average pore diameters of 5 µm. Many of the products produced by Blasch have complex shapes that could not be produced with other existing ceramic technology. Blasch's unique technology is protected by several patents.

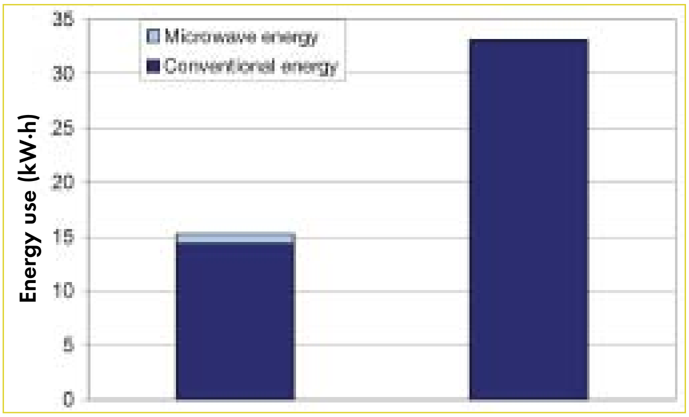

Fig. 1 Comparison of the energy consumption for MAT calcining vs. conventional calcining. Note that the small amount of microwave energy applied reduced the total energy consumption.

The firing time for these products is relatively slow to prevent cracking of the parts. To better serve its customers, Blasch is constantly striving for high efficiency and just-in-time manufacturing. This is one way for U.S. manufacturers to stay competitive. Faster firing cycles decrease the turnaround time, decreasing inventory and work in process.

Using MAT, Ceralink demonstrated feasibility of 10 times faster firing using Blasch test bars in a MAT electric lab kiln. The properties of the bars were comparable with bars fired using Blasch's current process. The next step was to fire small Blasch parts in the lab kiln. After the process had been successfully demonstrated on the laboratory scale, the firing was scaled up.

Ceralink recently demonstrated successful MAT firing of SiC sleeves using a five-times-faster heating rate in a 30 ft^3 MAT electric kiln. The fast heating was possible because of the temperature uniformity of the part. This faster heating represents a 500% time savings and an estimated 41% energy savings over the current process.

Another ceramic manufacturer exploring MAT is Lapp Insulators. Lapp is a producer of porcelain and Al_2O_3-replaced porcelain ceramic insulators in Rochester, N.Y. Off-shore competition has forced Lapp away from the production of small insulators into large specialty insulators. Lapp has expertise in fabrication and firing of these large insulators. Their expertise combined with the high cost of shipping such heavy products overseas keeps Lapp competitive in the insulator market.

The move to larger insulators creates other challenges, such as extremely long firing times, on the order of several days.

Fig. 3 Blasch SiC sleeves fired in a 30 ft^3 MAT electric kiln. These parts were successfully fired five times faster than Blasch's conventional firing cycle.

Fig. 4 Example of a Lapp insulator sample that was fired in a lab-scale MAT furnace at ~10 times the conventional firing rate.

Some of these insulators are approaching 6 ft tall and weighing more than 400 lbs. By their nature, these products are highly insulating, making heating them particularly difficult. MAT is well-suited to this type of product, where the microwave is critical to assist in heating the core of the insulator. Ceralink has performed feasibility testing on a sample-size insulator (10 in. tall, 20 lbs) in an electric MAT furnace. Several samples were fired ~10 times faster without cracking. Lapp is analyzing the samples for density and carbon content. The next steps of this project will be to refine the lab-scale firing process and then move into scale-up MAT firing of multiple parts.

Calcining Powders

Another successful example of MAT for ceramic applications is calcining of nanosized electroceramic powders. Fast heating is valuable in maintaining fine grains during calcination or sintering. The drive toward smaller, streamlined electronics requires finer-grained electrocer-amics. For many products, this means ultrafine starting powders are required. Ceralink is using MAT to calcine nanograin powders, produced by the mixed oxide method. One example is calcining $BaTiO_3$ for multilayer capacitors (MLCs). Grain size is particularly important for MLCs because they require a certain number of ceramic grains across the thickness of the layer. In order to make thinner capacitors, finer grains are required.

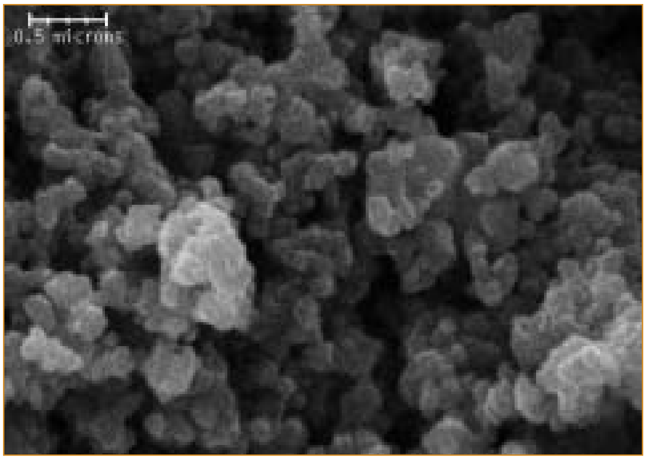

Fig.5 MAT-calcined barium titanate powder with an average particle size of 170 nm.

To make $BaTiO_3$ capacitors, $BaCO_3$ and TiO_2 powders are calcined together. In the ideal calcining process, just enough heat is applied to drive the reaction, and then the heat is removed so that the product does not form hard agglomerates or undergo grain growth. Slow heating rates, and high-temperature dwells are generally required to fully react the two powders, and this time at temperature promotes grain growth.

Ceralink has demonstrated that the reactants can be heated with MAT to form $BaTiO_3$ at 200–300°C lower temperature and at one-fourth of the dwell time. This resulted in fully reacted powders with a grain size of 120–170 nm (Fig. 5). In order to obtain complete reaction without microwave heating, the grains grew to 550 nm. In this case, it was demonstrated that MAT could reduce the time and energy consumption and produce a superior product that is otherwise difficult or impossible to make using conventional techniques.

Ceralink worked with Ferro Corp. (a ceramic powder manufacturer) to test MAT-calcined $BaTiO_3$ in MLCs. The performance results were encouraging, which led to the design of a scale-up MAT rotary calciner. This MAT system can be used to calcine many oxide ceramics, including PZT, PMN, sensors, actuators, relaxors, accelerometers, dopants, fuel-cell electrodes and pigments.

Useful for Many Applications

MAT offers ceramic manufacturers a profitable edge in today's competitive global market. As MAT capabilities are further tested and explored, it is proving useful for an increasingly wider variety of applications in the ceramic industries, including production and manufacturing, research, product development, rapid prototyping, quality control, sintering, calcining, heat treating and binder removal.

Significant cost savings and improved product opportunities can be gained by the ceramic industries through the implementation of MAT manufacturing. Key products and markets served by this innovative technology are electroceramics, structural ceramics, nanomaterials/nanotechnology, automotive parts, dental ceramics, biomaterials/orthopedic ceramics, porcelains, high-temperature materials, wear parts, abrasives, sanitaryware, tableware, brick (clay and nonclay) and refractories.■

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