

The newest generation of lightweight, low-mass kiln furniture can help pottery producers save energy, improve productivity—and increase profits.

# Lighten Up

by Michael Arbini and Marshall Browne

Think about your kiln shelves for a moment. Chances are they're large and heavy, and consume more energy during each firing cycle than your products do. Now, imagine decreasing that block of kiln furniture by 50% or even 75%. Impossible? Not with the newest generation of kiln furniture, which is produced from several types of advanced silicon carbide (SiC) refractory materials.\* These advanced SiC refractories are 10 to 28 times stronger than traditional SiC and cordierite refractory materials, which allows for substantially lighter kiln furniture components, such as plates (shelves), support beams and support posts. The important properties of these advanced SiC materials are summarized in Table 1 (p. 4), along with the properties of traditional SiC and cordierite for comparison.

Advanced nitride-bonded SiC (NSiC) kiln furniture in particular offers several advantages over traditional SiC and cordierite kiln furniture for pottery kiln applications. Higher strength allows for smaller cross-sections and lighter components. For example, an advanced NSiC kiln shelf is thinner ( $\frac{5}{16}$  in.) than the typical  $\frac{3}{4}$ - to 1-in.-thick traditional kiln shelf. Thinner cross-sections and excellent thermal properties result in faster heat transfer and greater energy efficiency—as a result, firing cycles can often be completed in less time using less energy. And, depending on the percentage of the total kiln load devoted to kiln furniture, thinner kiln shelves can significantly reduce the total load density while increasing ware capacity.

These and other benefits are helping an increasing number of production potters reduce production costs while increasing profitability.

## Advanced NSiC Benefits

Advanced NSiC kiln furniture—especially in the form of kiln shelves—has been steadily finding its way into a number of gas-fired pottery kiln applications for the last several years due to its unique performance characteristics and lower cost when compared to other advanced SiC materials.\*\* (Although advanced NSiC kiln furniture has a higher initial cost than traditional SiC or cordierite kiln furniture, a thorough economic analysis typically indicates a rapid return on the investment.)

The light weight of an advanced NSiC kiln shelf is one of its most heralded attributes, because less heavy lifting is required when stacking and unstacking kiln loads. For example, a 24 x 12-in. advanced NSiC shelf weighs just 8 lbs, compared to up to 21 lbs for the same size traditional SiC or cordierite shelf. This alleviates many of the ergonomic and safety concerns often found in pottery production facilities.

The reduction in energy consumption is also an attractive benefit. Calculations based on a 24 x 12 x 1-in. cordierite shelf compared to a 24 x 12 x  $\frac{5}{16}$ -in. advanced NSiC shelf fired at 2228°F with a cost of electricity at \$0.10/kWh demonstrated that it cost \$0.30 (3 kWh) to fire the cordierite shelf and \$0.12 (1.2 kWh) to fire the advanced NSiC shelf—a savings of over 50%.



An advanced SiC kiln car using reaction-sintered, silicon-infiltrated SiC beams and posts to support perforated cordierite kiln shelves. Photo courtesy of AC products in Apple Creek, Ohio.

\*Available commercially under the trade names Advancer® (advanced nitride-bonded SiC, U.S. patent no. 4,990,469), Crystar® 2000 (recrystallized SiC) and Silit®SK (reaction-sintered, silicon-infiltrated SiC), manufactured by Saint-Gobain Ceramics.

**Table 1.** Kiln furniture material properties.

| Typical Properties                                      | Traditional Materials |                 | Advanced Silicon Carbides |                   |                    |
|---|-----------------------|-----------------|---------------------------|-------------------|--------------------|
|   | Cordierite            | Silicon Carbide | ReSiC <sup>1</sup>        | NSiC <sup>2</sup> | SiSiC <sup>3</sup> |
| Maximum Use Temperature (°F)                            | 2336-2372             | 2822            | 2912                      | 2642              | 2462               |
| Density (lbs/ft <sup>3</sup> )                          | 119-131               | 162             | 160-175                   | 175-180           | 185-195            |
| Porosity (%)  | 20-30                 | 15              | 15-18                     | <1*               | <0.1               |
| Modulus of Rupture >2192°F (psi)                        | 1450-2900             | 8990            | 12,000-14,000             | 24,000-27,000     | 37,000-40,000      |
| Modulus of Elasticity 77°F (kpsi)                       | 2900-5800             | 23,200          | 30,000-35,000             | 32,000-34,000     | 48,000-54,000      |
| Thermal Conductivity (BTU-in/hr-ft <sup>2</sup> -°F)    | 7-10                  | 97              | 145-180                   | 85-125            | 165-270            |
| Thermal Expansion (x 10 <sup>-6</sup> F <sup>-1</sup> ) | 1.4-1.7               | 2.8             | 2.5-2.7                   | 2.4-2.6           | 2.4-2.7            |

1. Crystar® 2000 recrystallized silicon carbide; 2. Advancer® advanced nitride-bonded silicon carbide (U.S. patent no. 4,990,469); 3. Silit®SK reaction-sintered, silicon-infiltrated silicon carbide

\*Double-fired NSiC

Additionally, advanced NSiC kiln shelves are made flat and stay flat. The manufactured maximum allowable deflection for a shelf is 0.003 in. per inch measured across the diagonal, and the shelf will remain flat after many firings to cone 10 or 12 under heavy loading. At these temperatures, a 24 x 12-in. shelf will easily support a uniform load of 200 lbs (supported at three points) without warping after repeated firings. Advanced NSiC structural beams are also often used to support heavier traditional SiC and cordierite shelves to minimize warping.

Pottery producers have also discovered that advanced NSiC kiln shelves require less maintenance compared to conventional kiln furniture. Because the typical porosity of traditional SiC and cordierite shelves ranges from 15% to 30%, glaze drips fuse onto and into the surfaces of these shelves and require grinding for removal. The porosity of advanced NSiC

shelves, however, is less than 1%, which makes it very difficult for glaze drips to get a firm grip on the surface. Many users report that glaze and soda drips are easily scraped off an advanced NSiC shelf without grinding and without the use of any kiln wash. While the exclusion of kiln wash is not necessarily recommended for all users, the extremely low porosity of advanced NSiC shelves does significantly reduce or eliminate other labor-intensive maintenance operations.

### Firing Atmospheres

Although advanced NSiC kiln furniture is primarily used in gas-fired kilns, it can also be successfully used in some soda-, wood- and electric-fired applications.

**Soda Firing.** Advanced NSiC kiln shelves can be used in soda firing when soda is introduced indirectly into fireboxes using wet or dry methods. Due to the extremely low porosity of the shelves, soda drips are usually easy to remove by hand scraping after each firing. However, advanced NSiC shelves are not recommended for applications where water/soda combinations are sprayed directly onto the shelf, because they are susceptible to thermal shock failure under these conditions. In these cases, a thicker traditional SiC shelf should be used.

**Wood Firing.** Advanced NSiC kiln shelves have also been used successfully in wood-fired kilns. However, the shelves must be placed so they are not subjected to direct flame impingement or uneven

temperatures. In wood-fired kilns with multiple chambers, the shelves have been used successfully in the second and third chambers, where temperature rises are gradual and direct flame impingement is not an issue. If these chambers are stoked with wood at later stages of the firing, it is important that temperatures are already high enough to allow for a gradual increase, and/or that the shelves are stacked or shielded in a way that prevents direct flame impingement. A combination of advanced NSiC shelves and traditional SiC shelves is often a good option in areas where temperature uniformity is a problem.

It is also worth noting that an advanced NSiC shelf is likely to exhibit more profuse glass dripping from the alkalis present in wood-fired atmospheres. A traditional SiC shelf will exhibit a certain amount of glass dripping in wood-fired atmospheres due to oxidation; however, the problem is compounded with an advanced NSiC shelf because of its higher surface area of silicon carbide (i.e., fine grain sizing and low porosity). An advanced NSiC shelf also has a protective oxide (glass) layer, which is intentionally formed during manufacturing to further protect the shelf from the destructive effects of oxidation. When excess alkalis are present, which is the case when wood is a fuel source, the alkalis will flux the glass layer and lower its viscosity, causing the glass to drip or foam more readily. The effect is less pro-



Fired student work on advanced NSiC kiln shelves, ready to be unloaded. Photo courtesy of Northern Clay Center, Minneapolis, Minn.

\*\*Note: Certain application variables such as temperature, load and ware compatibility may require the use of other advanced SiC materials. It is always best to consult an application specialist for material recommendations.

nounced in second or third chambers where direct wood stoking is minimal.

**Electric Firing.** Advanced NSiC kiln shelves are also starting to be used in top-loading resistance coil element kilns, where their light weight and lower mass offer several advantages over traditional shelves. For instance, while a 1-in.-thick cordierite shelf has been the standard choice for electric kiln firings to cone 6 and above, it also consumes a lot of energy and stacking space. This is especially the case with 7- to 20-cubic-foot top-loading kilns, where space is at a premium. Not only will an advanced NSiC shelf stay flat in this application, but its  $\frac{3}{8}$ -in. thickness also allows for more stacking space and reduced energy costs. It is also easier to lift in and out of top-loading kilns due to its lighter weight. The initial investment for the advanced NSiC shelves is significantly higher than cordierite shelves in electric firing applications; however, it is easy to realize a substantial return on investment when energy and productivity savings are considered.

It should be noted that there has been a long-standing belief in the pottery market that silicon carbide shelves cannot be used in electric kilns due to the risk of electrical shock. Silicon carbide is an electrical conductor; however, the electrical resistance of advanced NSiC shelves depends on several variables, making the likelihood of an electrical shock minimal. As with any type of powered equipment, observing common sense rules, precautions and maintenance recommendations will eliminate potential hazards. For instance, advanced NSiC shelves should not be used in kilns that are in poor repair with unpinned elements protruding out of their grooves, and an operator should never reach into an electric kiln unless the power is turned off. More detailed information can be obtained from an application specialist.

### Product Suitability

Advanced NSiC shelves can be used with a number of different pottery products. One of the most logical applications for these shelves is in tile production firings, where



Glazed work being loaded for firing on an advanced NSiC shelf and lug post system. The ceramic barrier plates under the pots are used to contain the crystalline glaze run offs—no barrier is needed in a normal firing. Photo courtesy of Campbell Studios, Inc., Cambridge Springs, Pa.

the advanced NSiC material provides a flat surface that remains flat after repeated firings to cone 10 and beyond. Energy savings and increased stacking space are other advantages. Due to the manufactured flatness uniformity of the shelves, tile can often span the seam of two shelves butted together without noticeable deformation, provided all posting is level. However, care must be taken in placing the tile on the shelves to avoid temperature differences that could possibly lead to thermal shock failure—especially when firing  $\frac{3}{8}$ -in and thicker tile. For example, if thick tiles are placed to cover an entire shelf except around the edge, the exposed edge can act as a cooling fin while heat is retained under the tile, and the temperature difference could possibly lead to thermal shock failure.

Many potters choose advanced NSiC shelves specifically because of their ability to resist glaze from fusing onto the shelf surface. However, unglazed porcelain foot rings and pot bottoms will fuse onto a shelf surface so tenaciously that pots cannot be removed without breaking off the fused portion. This effect is similar to that seen in a wood-burning kiln—the alkalis in the porcelain glaze migrate under the ware and flux the glass layer of the shelf, especially at higher temperatures. This lowers the viscosity of the glass layer, making it very sticky.

These potentially destructive effects can be overcome by using an appropriate high-alumina kiln wash when firing

porcelain bodies. Due to the advanced NSiC material's extremely low porosity, kiln washing a shelf is like trying to re-glaze a fired pot that has already been glazed; however, pre-warming the shelves to promote drying can facilitate kiln wash application. Additionally, several thin coats of an appropriate low-clay-content wash will have less of a tendency to lift off during drying and firing. A fired coating specifically designed for porcelain compatibility and adherence to the advanced NSiC shelves can also be used. It is best to consult an application specialist for a specific kiln wash or coating recommendation.

### Application Considerations

Although advanced NSiC kiln furniture offers a number of benefits compared to traditional kiln furniture, as with any product, some limitations exist. Potters must examine their specific kiln and firing applications to determine if advanced NSiC kiln furniture is the right choice for them.

Users must understand that the advanced NSiC material is vastly different than traditional SiC and cordierite materials. While advanced NSiC kiln furniture is much stronger and can support far heavier loads, it is also more susceptible to mechanical damage or breakage if mishandled. Care must also be taken to prevent advanced NSiC kiln furniture from being exposed to prolonged moisture, such as repeated condensation or rain, because it has a tendency to dry very slowly. Even though the porosity of the advanced NSiC material is extremely low, prolonged exposure to moisture can still penetrate into the part. If an exposed part is fired under normal conditions, the low porosity does not allow moisture to readily escape, and a steam explosion can occur. It is therefore recommended that the kiln furniture be stored in a dry, enclosed area that will not be exposed to inclement weather or ground moisture. If the kiln furniture is inadvertently subjected to moisture, it must be dried in accordance with a detailed drying schedule prior to normal use. (An application specialist can provide assis-



Glazed pots on advanced NSiC kiln shelves ready to be fired in a multi-chambered, wood-fired kiln. Clay wadding is used with the dense brick supports. Photo courtesy of Richard Bresnahan at Saint John's University in Minnesota.

tance in this situation.) It should be noted, however, that the use of an appropriate kiln wash is very acceptable and does not constitute a moisture concern.

One of the most important considerations when using advanced NSiC kiln shelves is avoiding rapid or uneven heating and cooling that could possibly lead to thermal shock failure. Extreme temperature differences lead to unequal expansion within the

shelf, resulting in high internal (thermal) stresses. Sometimes these stresses are high enough to trigger a crack. Think of it as pouring a liquid at room temperature on ice—the extreme temperature difference causes the ice to crack. Traditional SiC and cordierite shelves are typically coarse-grain, pressed, porous compositions; as a result, a thermal shock crack may start at one edge and stop a short distance into the shelf by

finding a spot to “dead-end.” An advanced NSiC shelf, however, is a fine-grain, slip-cast composition with a much higher density, and a thermal shock crack will almost always propagate through the shelf and cause shelf failure.

For this reason, advanced NSiC shelves are not recommended where direct flame impingement occurs, such as Raku firing and some wood-firing applications (as described previously). Similarly, the shelves should not be used whenever rapid and potentially uneven temperature changes are anticipated. Forced-cooled firing profiles are not recommended unless they are absolutely controlled for temperature uniformity.

Some advanced NSiC shelf failures have been observed on the bottom layer of kiln car settings. This is most likely caused by cold air being drawn through leaky car seals when the kiln is shut off, or by excess heat retention of the car bed when compared to the rest of the kiln. For this reason, it is typically recommended that the bottom shelf layer be composed of thicker traditional SiC parts.

Additionally, excessively massive support posts should not be used with advanced NSiC shelves. Commercially extruded posts with a hole through the center are acceptable, as are dense brick soaps and advanced SiC beams and beam sections used vertically or horizontally. Full-size dense brick used as posts can retain enough heat at the support area to cause temperature differences during cooling that can lead to thermal shock failure in the kiln shelf. Such cracks usually follow a crescent shaped path around the offending post (brick). Clay wadding can also be used to help reduce the likelihood of these problems.

### A Cost-Conscious Choice

Advanced NSiC kiln furniture offers many advantages over traditional kiln furniture in a range of pottery production applications. Its substantial strength allows users to significantly reduce their refractory-to-ware ratio, resulting in increased productivity, and its thinner cross-sections (i.e., less refractory mass) and excellent thermal properties provide faster heat transfer and substantial energy savings. Any increase in energy costs makes the return on investment even more attractive. Other advantages include light weight, flatness retention, less maintenance and longer life.

Given these benefits, it is not hard to understand why many potters are now using advanced NSiC kiln furniture—and why many more are evaluating it for use in their applications. 🌐

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