Temperatures inside of the kiln can reach 1,300 °C.

1.000 years of beauty: wings to the cosmos

Kiln-fired reproductions of legendary celedon porcelain boast greater heat tolerance than NASA tiles

Art and science.
Tradition and innovation.
Inspiration and raw data.
Failure and success...
Sometimes thinking in terms of black and white can be a useful tool for gaining a clearer understanding of ordinary phenomena.
But if we polarize our thinking too much, we miss the infinite possibilities in between.
By allowing more freedom and flexibility in our thinking, we create the possibility of taking an idea firmly rooted in tradition and sending it off into space.

Celedon porcelain: a gift from the gods
The color of the sky after a rain

"Your efforts have hit a wall? It's not useful to think in terms of a wall as it's quite natural for us to fail. But if we continue working, we are able to discover something new and interesting from our failures."

As the euphoria and boisterousness of spring hit its peak last April, Koichi Shimada held a pottery exhibition in Tokyo's fashionable Ginza shopping district. The featured celedon porcelain pieces drew on powerful, ancient traditions to create a gallery atmosphere of refined elegance—in sharp contrast to the modern hustle and bustle on the streets outside. Even without being a pottery expert, if we were to use such pieces in our daily lives, they would surely restore in us a timeless sense of elegance and grace.

All of the pieces on display had been fired in the same kiln, a fact we would not appreciate until much later. Mr. Shimada is known for his work in applying new scientific methods toward making pottery and we visited his exhibition to arrange an interview. When asked how he overcame the "walls" he encountered as he broke from tradition, he answered with the quotation at the top of this article.

"Sometimes people behave like robots, trying to do everything by the books. If they get results that are different from what's in 'the manual,' they think they're a failure and stop. I am different in the sense that I think the manual itself is wrong. In this context, I think about how to proceed, and continue my trial and error with the full knowledge I am going to fail. The more possibilities you try, however, increase your chances of finding something interesting. Actually, I don't think in terms of walls at all. I just consider them as part of a process leading to success. As for celedon porcelain, we don't have a manual, so it's very easy for me."

Celedon porcelain was at its artistic peak in China during the late 11th Century. Bowls and plates 'Jokanyo' were fired in special Joyo kilns to produce their characteristic 'sky-after-a-rain' color, which was revered as a gift from the gods. When Mr. Shimada visited Taiwan 26 years ago as a high-level business executive, he was enchanted by its famed the National Palace Museum, an experience that would change his life. Only some 40 pieces of Jokanyo pottery still exist in the world, and recreating the process once used to make Jokanyo pottery was considered impossible.

Undaunted, some years later Mr. Shimada quit his company to devote himself to rediscovering this process. After 20 years of trial and error, thoroughly grounded in modern scientific methods, he had earned enough of a reputation that he was invited to exhibit at Taiwan's National Museum of History, back in the country that had given him his original inspiration.

During my visit to his Ginza exhibition, I didn't quite understand Mr. Shimada's relationship between hating "the manual" and not being afraid of failure, while still using scientific methods in his

research. He seemed to have no plans for success, yet totally applied himself to the rigors of scientific research.

A key approach to understanding materials
Seeking the wisdom of our ancestors

In May, I visited Mr. Shimada's studio, located about ten minutes by car from, coincidentally, Shimada train station in Shizuoka Prefecture near Mt. Fuji. Located on top of a hill, it commands a lovely view of the area's renowned green tea fields. He first showed me his kiln. Whenever his assistant put in another load of wood, I could see the pillars of flame inside, which looked like monsters. It made an unusual picture to see a personal computer next to the kiln, which was making the area so hot I said it was like a sauna. "No," said his assistant as he loaded in more wood, "this is hell." Mr. Shimada then showed me a darkened house next door that was over 100 years old.

"While the writings of our ancestors can teach us many things, there is important information that cannot be learned from books. For example, it turns out to be important when the pine trees that provide fuel for our kiln are harvested. The best time is November through March, because that's when the pine tree is sleeping, and not absorbing water. Later, as it gets ready for spring, it pulls water from the ground increasing the chances the wood will be rotten, or crack during the drying process. Because it adversely affects the performance of wood for fuel and construction, it would be foolish to ignore this. Today's wooden buildings only last about 25 years. But this house is over 100 years old and will survive at least another 100 years."

Mr. Shimada explained that the correct use of technology, as with wood drying

A personal computer next to a kiln displays temperature and carbon dioxide levels at eight locations inside the kiln.

machines, should take into account the experiential knowledge of our ancestors.

"We can't find a book that will tell us how to make celedon porcelain. After returning from Taiwan and attending many exhibitions of celedon porcelain, I saw that no one was making Jokanyo pottery. Personally, I think it's wrong to call pottery celedon porcelain based solely on its characteristic greenish-blue color. I wanted to understand the difference between the original celedon and these modern replicas, so I began a thorough investigation of the original."

We've all seen television programs or magazine articles that show a potter working with soft clay. Natural clay is mainly comprised of quartz and feldspar mixed with kaolin, a white clay adsorbent. It varies in quality depending on where it is from, and on the amount of iron and other impurities. There are never-ending variations of pottery material.

Beyond the clay itself, a key material consideration is the glaze. Glaze was an accident, originally discovered during the firing process when ashes flew up onto pottery pieces leaving an acid residue that melted into a glass-like glaze. I'm sure ancient potters were quite surprised to see their pieces shining when they took them out of the kiln. This gave rise to a new technique, in which a glaze of melted feldspar and ash was intentionally applied to pottery before firing. It was later refined to produce different colors by adding iron, copper and other materials.

The clay material you select has a major influence on the "expression" of the pottery. After visiting many university laboratories, Mr. Shimada began serious research into materials at Shizuoka University's Department of Agriculture. In his quest to recreate the beauty of 1,000 years ago, he applied the science of inorganic chemistry.

"By performing a quantitative analysis, we can determine what kind of materials they used to use. Then we can ascertain the closest equivalent we have in modern materials, or what combination might best reproduce the original."

For every type of clay that is used, an appropriate firing process must be selected. As a general rule, the higher the temperature, the more the pottery expands. But in reality, some elements in the clay melt before others and seep in between the solid materials, which causes some pottery to actually shrink.

"I can identify the optimum temperature for firing by calculating a melting point based on the percentage of various materials in the clay," Mr. Shimada explained. To obtain high-quality data, a precise monitoring system that utilizes eight sensors was installed inside the kiln.

A scientific view of wood-fired kilns

The artistry of a flame

As one of Mr. Shimada's assistants turned to leave, he said, "The next shift comes on at 3:00 p.m., and I'll be back at 3:00 a.m. tomorrow." Maintaining the wood furnace for the kiln is a 24-hour-a-day job, and this kind of pottery takes four days to fire. Mr. Shimada explained that temperature changes between 400 and 600°C, the critical range for expansion and contraction, must be done very slowly.

"Although we have to go to a lot of trouble, flames running around inside the kiln have a far more artistic effect than heat from an electric kiln. During the four-day firing period, tremendous variation is possible. It's kind of like comparing the food made each night by a real chef in a restaurant to mass-produced microwave dinners."

Because of the flame's artistry, even if the materials are exactly the same, we can get different colors. According to a book I read on pottery making, if you have more oxygen, the iron inside the glaze material becomes yellowish. If you have less oxygen and more soot it becomes blue. The bluish color of celedon indicates there was probably less oxygen present, but Mr. Shimada did not take this for granted.

"We could assume celedon is fired with less oxygen because of its bluish color, but there is no potter who can scientifically explain what percentage is due to oxygen and what is due to carbon monoxide. Since I am no one's student, I have to do everything myself and my first thought was to obtain some concrete data."

Kouichi Shimada was born in 1937 in Fukuoka Prefecture on Japan's southernmost main island of Kyushu. He was the recipient of the "Japan Pottery Exhibition Award" and many other international pottery awards. He was also invited to exhibit his works at Taipei's National Historical Museum.

Do you accept the experiential knowledge of our ancestors without confirmation from scientific research and hard data?

"Of course not. But what was possible 900 years ago—without electricity, without quantitative analysis, and without advanced sensors—cannot be repeated today. So what's wrong? It's quite natural for me to use science to answer this kind of question."

In addition to temperature sensors, Mr. Shimada added sensors to detect carbon monoxide and carbon dioxide. Output data is sent via LAN for analysis and the results are displayed on a monitor next to the kiln. While this process provides

concrete data for making celedon pottery, it's impossible to create a manual on how to do this. There's a lot of trial and error. Mr. Shimada has gathered much data and performed many experiments using this kiln. Would it be fair to say that for such data to lead to success, there must be many failures along the way?
"In my case, I have a dream to actually produce a physical object, and that is far more important than establishing a new theory."
Much pottery has been produced as the result of accidents or unexpected incidents, and some pieces are now art objects of great historical significance.
"It's true that many great works were achieved like this, and I am not against appreciating them. But I certainly want to know how they were made, a curiosity that is surely inside all of us. But it's been 1,000 years and we don't have some of these answers, which means modern civilization is not quite as advanced as we might think. I think it's time we merge our knowledge of science with the experiential knowledge passed down through the ages."

Save the Japanese space shuttle!
Pottery that flies through the cosmos

Pottery and porcelain are usually distinguished from one another by material composition, firing temperature, and the fact they are fired in different kilns. Mr. Shimada has ignored conventional wisdom and uses the same kiln for both.
"Even within a single kiln, there are so many different firing conditions. I use a sensor to observe this in great detail and then I apply this information to put each piece in the most appropriate place for firing."
Even though he adjusts the oxygen level and sets other special conditions, Mr. Shimada uses the same kiln to fire all of his pottery.
"That's not quite right. If you read a pottery book, they only mention two possibilities: firing with lots of oxygen, or firing with less oxygen and lots of soot. In reality, there isn't just this simple duality. A better way to put it would be that one type of pottery requires a lot of deoxidization and the other does not."
We have two extremes, and in between, a range of other possibilities. It's becoming clear that a great deal of

Artist's rendering of HOPE-X space shuttle, courtesy of National Space Development Agency of Japan (NASDA).

■ Comparison of first-generation NASA tile (HTP-6-22) characteristics with target values for NASDA thermal tiles

	First-generation U.S. tile (NASA)	NASDA target value
Specific gravity	0.10	0.1 or less
Approximate melting point	Approx. 1,500 °C	1,500 °C or higher
Thermal expansion coefficient	2.8×10^{-6}	2×10^{-8} or less

Note: NASDA is currently working to reduce costs as well as improve productionmethods.

An ultralight weight, extremely heat-tolerant tile whose surface has been glazed. Current specific gravity is 0.132.

scientific research went into creating the variety of pieces on display at Mr. Shimada's Ginza exhibition.
Today, Mr. Shimada's kiln is being used to make pottery for space. NASDA (National Space Development Agency of Japan) is planning to launch a Japanese space shuttle named HOPE-X and Mr. Shimada has been engaged to develop extremely heat-tolerant tiles for the shuttle's outer shell.
"One of my friends working for NASDA asked me if I could make a heat-tolerant tile. I said he could buy one at a hardware store, but he explained to me it's not a bathroom tile. When I asked what kind of tile they needed, he sent me a very detailed specification."
And that was only the beginning. The NASDA specifications for specific gravity, heat tolerance, melting point, and thermal expansion coefficient must all be achieved with better cost efficiency than tiles made for the NASA space shuttle.
"At first, I thought this was impossible. But after a lot of experimenting, we were able to make the material lighter by dispersing small air bubbles into the tiles. Fortuitously, this also improved its heat tolerance."
The new tile material is a mix of inorganic matter and traditional pottery materials, all of which are ground into a fine powder and mixed with sawdust. During firing the sawdust disintegrates, leaving small holes in the material that make it look like pumice. Polystyrene is also part of the mix. Currently, the specific gravity of this tile material is 0.132, about one-seventh that of water. If you hold a sample in your hand, it feels as light as Japanese wheat gluten cake. I wonder whether it will be strong enough. The melting point is 1,700°C, which is considered sufficient to maintain the material's integrity during entry to the atmosphere.
"In this case, theory did not come first. We try everything, and if something works, we explore that direction in depth. We'll try and come up with a theory later. This might not be the most logical way to proceed, but I find it similar to the way inventions came about many years ago. If children are told to play with certain objects, they always create new ways to enjoy them."

Where once there was only darkness, a flame is beginning to burn. Some of the stories we have been privileged to enjoy are starting to impact our whole way of looking at life. In fact, we are completely overwhelmed, intoxicated with the euphoria of all these new possibilities. Instead of taking a taxi back to the train station, we walked down the hill, passing through green tea fields and listening to the caw of a crow.

THE COSMIC DINER

Hiroshi Watanabe
Senior Researcher,
Products Development Office,
Central Research Institute,
Maruha Corporation.

When you think of astronaut food, perhaps the image of squeezing something out of a toothpaste tube comes to mind. While this was true in the 1960s when space travel began, things have changed dramatically. To bring ourselves up to date, we interviewed Mr. Watanabe, who helped develop a special Japanese food menu for the 1994 space shuttle trip of Mrs. Chiaki Mukai.

"There isn't a specific definition of 'space food.' So although we produced food that conformed to NASA standards, we tried to offer her what a typical Japanese family might eat. In the end, the only difference was that soupy or juicy foods were made more sticky so they could be consumed under zero gravity conditions."

Inside the shuttle, Mrs. Mukai had a Japanese food party with her fellow crew members. The menu featured meat, potatoes, salmon steak, spiced rape-flower blossoms, rice pilaf, and other items that represented the types of foods found on ordinary family dining tables all over Japan. They could only enjoy such foods in space because of advancements in preservative technologies, most of which were not motivated solely by the challenges of space.

"Freeze-drying, precooking, and applying ultrahigh pressure are all techniques currently used for processing food on earth. Our job was to determine which method was most suitable for preparing food for space."

If breakthroughs in preservative techniques continue at this pace, pretty soon it won't make much difference whether we're eating on earth or in space. So how does this ultrahigh pressure technique work?

"We sterilize food by placing it under extremely high pressure. Ordinary precooked food is also sterilized using high-pressure and temperature, but the extremes don't go much beyond those of an ordinary pressure. Ultrahigh pressure sterilization is a totally different technique that applies more than 4,000 atmospheric pressure. This technique, originally used for processing ceramics, reduces proteins at the microbe level, thereby killing germs."

The benefit of ultrahigh pressure is that, unlike conventional precooked packaged food, you don't have to apply heat to sterilize it. It's ideal for retaining the flavor of fruit and not destroying vitamins, which are very heat intolerant. For Mrs. Mukai's space shuttle flight, this technique was used to make a special fruit syrup. Of course, if you submit fruit to ultrahigh pressure, it will become as flat as a piece of paper.

"The air is what's really affected by pressure. Even under 4,500 atmospheric pressure, water only shrinks about 10% in volume. A boat that sinks to the bottom of the ocean, for example, doesn't diminish in size much at all. The air is what gets compressed and there's lots of air in fruit, so if you apply ultrahigh pressure, it will be crushed. But if you replace the air inside fruit with syrup, it will retain its shape."

In local supermarkets, we can already buy jam that has been processed using this technique, and some scientists want to start using it on sashimi.

"Because the proteins are slightly altered, the color can become dull. For example, applying ultrahigh pressure to sweet shrimp changes their color to that of boiled shrimp. Still, the taste and flavor is unchanged because it was never heated. This technique makes it possible for a completely raw egg to appear partially cooked. Certain hospitals have inquired about the possibility of using this sterilization technique with organ transplants. Since heat is not involved, it might be able to kills germs without harming a living organ, an exciting possibility."

Breakthroughs in one field of study can often be applied to another, with the most significant advancements usually applied to space technology. The universe is truly a fascinating place.

Courtesy of Maruha Corporation

The menu for Mrs. Mukai's space shuttle flight was developed based on recommendations from the public. Bottom from Left: spicy rape-flower blossoms, cooked tofu, filled with vegetables and chicken ("From the ground with love"), and deep-fried bean curd stuffed with vinegared rice. Middle from left: rice pilaf, salmon steak, boiled soybeans and vegetables. Top from left: meat and potatoes, mixed fruit, cosmic octopus balls (octopus pieces in batter).