

Using a CO₂ Laser-Firing as a Clean Production Method to Form an Electrical Conductivity Surface and Color-Changing on Craft Ceramic.

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Research Article

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Abstract

Craft ceramic is an old industry. Most craft clay needs to be fired in a kiln, but kilns are expensive and inefficient [Kiln firing thermal efficiency: Kiln body heat storage 18.67%, Exhaust Sensible Heat 45.9%, Heat loss from incomplete combustion 16.24%, Radiated Conduction and Other Loss of Heat 12.61%]. In order to change the color of ceramic, potters commonly use kiln reduction firing. This technique requires an additional step and more fuel, which creates more air pollution.

In this study, we used a CO₂ laser to fire craft clay and glaze. This process not only changes the ceramic's color but also changes the conductivity of the ceramic's surface. By changing the composition of the glaze, the ceramic's surface resistance was altered. Most kiln-fired ceramics are non-conductive because oxides are combined by covalent bonds. During the laser firing process, the covalent bonds become metal bonds.

This new firing technique produces ceramic products that are superior in terms of light, heat, magnetism, and electricity. Thus, laser firing adds more function to the final ceramic product than kiln firing does.

As opposed to kiln firing, there is no air pollution associated with CO₂ laser firing. In comparison to kiln firing, laser-firing reduces both heat waste and air pollution by 99%. This study is based on our patented laser ceramic reduction firing technique. (Taiwan, R.O.C Patent Number: I687394)

We recommend additional studies into laser firing in order to collect more data on laser-based ceramic production.

Range: 20W laser

1. Foreword

Kiln-based ceramic production is a costly and energy-intensive process. Some ceramic plants have been able to reduce air pollution through cleaner production techniques, which include facility replacement, technological improvement, process control, raw material and waste utilization, plant management, and worker training. These measures contributed to obvious progress in energy conservation and emission reduction in a ceramic tile plant in Guangzhou, China. (Yi Huangac, Jiwen Luo, BinXiaa, 2013)

However, kiln firing's low thermal efficiency means that only 2.91% of the energy produced in the kiln firing process is directly applied as heat to the clay body [Kiln body heat storage 18.67%, Exhaust Sensible Heat 45.9%, Heat loss from incomplete combustion 16.24%, Radiated Conduction and Other Loss of Heat 12.61%, Burning heat of clay body 2.91%]. (Cheng Daoxi, Zheng Wuhui, 1992)

To achieve a change in glaze color, kiln firing needs an additional reduction firing step, which creates additional air pollution. Most ceramic factories follow traditional kiln-based production processes. In this paper, we show that using a laser firing technique in ceramic production can achieve the same color-changing effect [reduction firing effect] without the corresponding air pollution of kiln firing.

Laser firing is a promising technique suitable for rapid prototyping and the development of new products. Laser firing can produce ceramics with non-equilibrium phase assemblages and hierarchically structured heterogeneities. And while the skill of kiln firing is hard to master, laser ceramic firing is more controllable, as it depends on an understanding of laser-materials interactions and control of structural heterogeneities. (Bin Qian & Zhijian Shen, 2013)

Comparing Fiber Laser & CO₂ Laser:

Fiber Laser:[Light wavelength]1070 nm~1080 nm, [Suitable cutting materials] metal.

CO₂ Laser:[Light wavelength]10640 nm, [Suitable cutting materials] Metal and non-metal materials other than copper and aluminum.

Experiment introduction

This study used a CO₂ laser to form an electrically conductive surface and color changes on craft ceramic.

By changing the clay and the glaze components, we were able to melt the ceramic with laser firing techniques.

The kiln-based craft ceramics process includes the following steps: 1) form the ceramics body by drawing, cutting, and/or sculpting, 2) dry the blank body, 3) glaze the body, and 4) fire the body in a kiln.

During the kiln firing process, the ceramic glaze melts and becomes smooth glass.

The melted glaze layer is waterproof. The glazed element will affect the color and finish of the final product. Metal or oxidized metal is the coloring agent used in glazes.

By changing glaze composition and firing technique, a potter can change the color and form of ceramic goods.

The glaze composition includes 4 parts. These are 1) flux: potassium, sodium, calcium, etc. 2) basic materials: alumina, 3) glass materials: silicon oxide, and 4) colorants: iron oxide, copper oxide, cobalt oxide, etc.

The kiln firing process can be divided into two steps, which are 1) oxidation firing; and 2) reduction firing.

Kiln energy sources include 1) electrical power [which also requires gas for the reduction firing step], 2) solid fuels (coal, wood), 3) liquid fuels (heavy oil, kerosene), and 4) gaseous fuels (gas, natural gas, etc.).

In the kiln firing process, a potter must control fuel and air to create an oxidizing or a reducing firing environment. This allows for a change in glaze color. Kiln firing is time- and resource-intensive. It requires an average of 8~168 hours to fire ceramic because the thermal efficiency of most kilns is less than 3%.

In this experiment, we used a CO₂ laser to fire clay and glaze. We then compared the final products of the kiln firing and laser firing processes.

This article includes the following sections:

1. Kiln firing is a traditional ceramic manufacturing technology. The kiln reduction firing process uses fuel control to reduce metal-oxygen. In a kiln that is heated to 950°C~1300°C, the oxygen atoms in the oxidized metal are combined with carbon atoms so that the metal displays its original color. In the kiln reduction firing process, the kiln expels large quantities of smoke and heat.

2. By changing the coloring metal in the glazes that we used, we achieved the results of ceramics reduction firing techniques while using laser firing.

Laser reduction firing creates no air pollution, requires no kiln equipment, and is less time-intensive than kiln firing.

3. Using the laser firing technique detailed in our patent (Taiwan, R.O.C Patent Number: I687394), we were able to create an electrically conductive surface on craft ceramic.

2. Comparing Co2 Laser Firing And Kiln Firing

2.1 Craft ceramic techniques

Fe_2O_3 and CuCo_3 are non-conductive ceramic metal colorants. A typical ceramic glaze component usually contains 0.5%–12% of these colorants. In kiln oxidation firing, the addition of 0.5% to 12% Fe_2O_3 changes the glaze color from light yellow to black. In kiln reduction firing, the addition of 0.5% to 12% Fe_2O_3 changes the glaze color from light green to black.

Reduction Firing

In a kiln with a temperature between 900°C ~ 1300°C , insufficient air for the amount of fuel creates an “incomplete firing”. The technique of incomplete firing is used to change glaze color.

High temperatures are required to convert a kiln’s fuel [solid or liquid] to gas. As the temperature becomes higher, the fuel conversion becomes faster. To achieve reduction firing, the fuel and air levels in a kiln must be controllable.

In wood-fired kilns, these temperatures ($900 \sim 1300^\circ\text{C}$) are required for changing the glaze color.

In the reduction firing process, the oxidized metal in the ceramic body and the glaze is changed to an unoxidized metal. This changes the ceramic’s surface color.

Hydrogen, carbon, and CO combine with oxygen, and the incomplete combustion gas steals oxygen from the glaze and the ceramic bodies. (Tony Hansen, 2015)

This reduction firing step requires heavy wood burning, the byproducts of which include heavy smoke and ash.

Therefore, kiln reduction firing is a major contributor to the ceramic industry’s pollution problem.

Copper red glaze, reduction firing, and kiln firing skills.

When kiln temperatures are high and ceramics are processed in an alternating cycle of reduction and oxidation firing, copper glazes display excellent reds and heat into colloidal copper metallic.

In oxidation firing, copper glazes display a green color. In reduction firing, however, they display a red or black color. The copper glaze component and the firing method both impact the final color of the glaze.

(S. F. BROWN,1959)(Arena, 2015)

According to available data on ceramic firing and heat energy consumption, only 2.9% of a kiln’s heat is directly used for ceramic body heating.

Most of the heat is wasted, and goes towards 1) Heating the kiln [3.12%], 2) Kiln body heat storage [18.67%], 3) Exhaust sensible heat [45.9%], 4) Heat loss from incomplete combustion [16.24%], and 5) Radiated conduction and other loss of heat [12.61%]. (Cheng Daoxi, Zheng Wuhui, 1992)

Ceramic reduction firing needs over 5~8 hours to work, and it expels pollutants like smoke and incomplete firing gases.

For workers in ceramic factories, reduction firing may lead to permanent health problems like lung damage and respiratory disease.

2.2. Refitting the CO₂ laser to fire craft ceramic.

The existing laser technology for ceramic firing is not yet perfect. Remaining challenges include the efficient production of lasers on a large scale and the development of high-power lasers and stable laser operations. (Akio Ikesue, Yan Lin Aung, 2008). New CO₂ laser technology could improve the economics and convenience of ceramics processing. The convenience and cost-effectiveness of these new lasers could make laser ceramic processing a mainstream technique. CO₂ lasers emit in the FIR at a wavelength of 10.6 microns, which is easily absorbed by most ceramics. They also have high output powers, which allow for high-speed processing and the processing of thick materials. (BAJRANG LAL,2013)

The laser used in our study has two firing types: cutting and engraving.

The laser focal length ranges from 0 to 60mm. To reduce variables, we set our laser power to 20W. -

For record a broader range of data, we experimented with defocused firing and/or removed the laser lens.

Laser cutting: [line cutting]

1) Laser setting: power at 5~50W, speed at 1~70mm/sec. The non-focal length is 0~40mm.

Laser cutting can quickly quickly create a "firing" effect on a ceramic surface. It also quickly displayed a heating result on the ceramic.

Laser Engraving: [surface flat cutting]

2) Laser setting: power at 5~50W, speed at 1~300 mm/sec. The non-focal length is 0~40mm. The engraving spacing 0.5~0.1mm

After using laser engraving settings, we observed a flat ceramic area with glass on its surface.

In order to reduce testing time, we first did full-range cutting (1~300 sec/mm) on the testing area.

In this way, we found the lowest effective power range. We then tested the defocused firing in the second step.

When performing laser cutting on a tile, we found that adjusting the laser's air blowing power affected the vitrified [glass] substance on the ceramic's surface.

Each laser has an air-blowing feature, which is a protective function that prevents the lens from smoking.

Laser firing makes ceramics liquefy rapidly and expand. During the laser firing, if the air-blowing function is too strong, the liquid ceramic will be blown away.

To prevent this problem, we adjusted the laser's air blowing pressure. We found that heavy air blowing made an etching effect, while light air blowing created glaze vitrification and welding effects.

Firing the same glaze with a laser and a kiln creates a very different physical reaction. The laser firing rate is more than 10,000 times faster than kiln firing.

2.3 Basic CO₂ laser formula

Using the following formula, we measured the laser's diameter in millimeters and calculated its power density.

The laser's light diameter is 2mm, the lens focus point diameter is 0.2mm, and the focal length is 20mm. When the focal length is over 40 mm, the laser's point diameter is 2mm.

3. Using Co2 Laser Firing To Form A Conductive Surface And A Reduction Firing Glaze Effect On Craft Ceramic

3.1 Craft ceramic and Laser 3D modeling

According to the above refit, we started firing the craft clay using a 20W laser.

Using a layered laser-firing method, we were able to achieve clay melt at a depth of about 2mm.

We cut the clay into a thin slice , and then added one new slice of clay on top of the already-fired layer. After completing several of these laser-firing processes, we cleaned the clay sample with water. After washing the clay, we were able to observe a vitrified [glass] tube in the clay. This observation confirmed that craft clay can be used in laser 3D modeling.

A Kiln firing system requires a lot of equipment, like a kiln, a gas tank, an electrical system, and a chimney. Because laser firing systems can be operated without kiln equipment and fossil fuels, they are much more cost-efficient.

3.2 Comparing kiln firing and laser-firing processes for ceramic

To test laser firing's ability to infer corresponding kiln temperatures, we changed the clay and used a kiln firing tool (Orton Cone 014, Temperature cone).

The following table shows our results:

Comparing kiln firing and laser firing

We fired clay and glaze with a 20W laser at 1~20mm/sec.

Building off of observations from our kiln firing experience, we changed several glaze elements and observed the corresponding laser firing results.

After changing the laser speed and the ceramic component, we observed a melting effect on ceramic that was fired via laser. Each element of the ceramic had a different melting temperature and heating rate.

As shown in the Orton Cone 014 firing temperature chart, the kiln heating rate is 30°C/hr. In other words, in kiln firing, energy accumulation is based on the kiln's heating rate. When enough energy is accumulated, the Orton Cone will melt or bend.

We used the laser to fire ceramic and the Orton Cone. The laser speed corresponded to the kiln's firing temperature. With different laser speeds, the energy accumulation created a bending [wave] texture on the ceramic and the Orton Cone.

In our tests, the laser's speed had a bigger impact on the final product than the laser's power did.

By using a lens to concentrate the laser on a 0.2mm focus point, we achieved a rapid heating effect.

Based on the melting speed we observed in the ceramic, the laser's heating rate is much higher than the heating rate of the kiln.

In the ceramic vitrification firing process, the kiln heated at a rate of 0.0416 °C/sec. The laser heated at a rate of 527.85 °C/sec. The laser's heating rate is 12688.7 times faster than the kiln's heating rate. According to these firing tests, kiln firing and laser firing create different results in the final ceramic product.

In laser heating, the glaze's melting pattern is different than it is in kiln firing. To figure out the differences between these two techniques, we compared ceramics fired by kiln with laser-fired ceramics. By recording the melting pattern of the ceramic surface and the laser speed, we found that the laser has a comparatively high heating rate.

When we set the laser's speed to 1mm~20mm/sec, we observed the following features:

According to kiln firing classifications, ceramic products are divided into blanks (body) and glazes.

The ceramic body's melting temperature must be higher than the glaze by over 100°C. This temperature discrepancy allows the product to maintain its shape and form a smoothly-textured glaze on its surface.

1. In this study, we used a laser (20W, 1~20 mm/sec) to fire ceramic materials. The Iron oxide in the clay showed a reduction color when laser-fired as it did in kiln reduction firings.

2. We also used the laser to fire the same clay at different temperatures. We studied 1) room temperature clay, 2) clay fired at 800 °C, and 3) clay fired at 1230°C. At each temperature, the result when fired at a slow laser speed (1~2 mm/sec) was the same. From this we conclude that the result of laser-firing is similar to that of kiln firing. In this way, we can measure the craft clay and the glaze's heat resistance.

3. When we changed the laser speed, the clay surface displayed a gradual change in texture. By recording the gradual change in texture, we observed the melting threshold of the clay.

At the same laser speed, an obvious wavy texture [a "melt & flow" texture] appeared on the ceramic surface of the clay at room temperature, the clay fired at 800 °C, and the clay fired at 1230 °C.

When compared, the kiln-fired and the laser-fired glaze and clay displayed different features.

The laser's high heating rate made the glaze's melt different than the kiln-fired melt.

With the laser's speed set to 1mm~20mm/sec, we fired the ceramic and recorded its surface melt.

1. When a 20W laser was used, the clay displayed a green color. When kiln fired, it displayed a brown color.

Our clay contains 2.3% iron oxide. Based on this percentage, we predicted that the iron oxide colorants would cause the clay color to change. We also predicted that the glaze's components would affect the laser firing result.

2. We observed an obvious wavy texture and melting texture on both the clay and the glaze when they were fired with lasers of different speeds at several different ranges.

3. When firing ceramic in a kiln, a potter adds clinker powder into the clay to reduce clay shrinkage.

For the above reasons, we believe that the obvious wavy texture and melting texture on the laser-fired ceramics are due to a difference in shrinkage rate. Each glaze has its own melting temperature.

For this reason, the obvious wavy texture appears on the surface of different ceramics with different glaze components that are fired at different laser speeds.

In our test samples (kiln firing with blanks bodies sintering at 1230°C and glazes melting at 1230°C), the blanks bodies (kiln fired at 1230°C, sintered) displayed an obvious wavy texture when laser fired at 5 mm/sec.

The glazes (kiln fired at 1230°C, melted) displayed an obvious wavy texture when fired with a laser at 14 mm/sec.

3.3 Laser energy calculation and kiln firing comparison

In this test, we used 20W lasers at several different speeds. We then plugged our results into the following equation:

Power Density/ speed (mm/sec) = Ceramic firing energy value

The laser's focal point radius was set to 0.2mm, and the laser's speed ranged from 1~20 mm/sec.

The laser's firing energy range is 159.1545709~ 7.957728546.

The power density of laser fired blanks (body 1250 °C sintered, kiln fired) is 53.05152364~31.83091418 (speed 3~5 mm/sec).

The power density of glazes (melted at 1230°C, kiln fired) is 19.89432136~15.91545709 (speed 8~10mm/sec).

According to data on kiln firing, ceramic products need a 250°C difference between blank (body) firing temperature and glaze firing temperature.

By calculating the energy and sample melting data of a 20W laser with a speed of 3~10 mm/sec, we were able to mimic the results of kiln firing at 1240~1000°C.

The laser's firing energy rapidly attenuated as the laser's speed increased. A low laser speed can therefore accurately predict the kiln firing temperature needed for a given piece of ceramic.

3.4 Using laser firing to form a reduction ceramic surface.

Laser firing is able to change the color of ceramic. To identify the reason for this, we conducted a firing test that compared glaze component changes in both kiln firing and laser firing. We studied a clay with 2.33% Fe₂O₃ and used glaze elements to form a clay-like component without Fe₂O₃. The laser firing melting energy was the same for both components.

We found that :

- 1)The clay containing 2.33% Fe₂O₃ displayed a green color when laser fired.
- 2)The glaze containing 0% Fe₂O₃ displayed a transparent color when laser fired.
- 3)The clay containing 2.33% Fe₂O₃ displayed a brown color when fired via kiln oxidation.
- 4)The glaze containing 3% Cu₂CO₃ displayed a green color when kiln fired.
- 5)The glaze containing 3% Cu₂CO₃ displayed a red color when laser fired.

Based on these observations, we concluded that laser firing can form a reduction firing effect in an oxidized environment. Using the data from this firing test, we obtained an invention patent [Taiwan, R.O.C Patent Number: I687394].

3.5 Laser firing Fe_2O_3 and the CuCO_3 to form a conductive ceramic surface

According to the above laser firing test, laser firing can create a reduction firing effect on ceramic. Our next test uses laser reduction firing to make oxidized metal conductive.

We began with non-conductive oxidized metals Fe_2O_3 and CuCO_3 . We then used a laser to fire those oxidized metals. After being laser fired, they became conductive but were very fragile.

We tried firing the oxidized metals again, this time on a ceramic surface. After firing and cleaning the surface, we achieved a conductive metal surface [CuCO_3 with 42Ω and Fe_2O_3 with 120Ω].

4. Results & Suggestions

A 20W laser that is fired at 10 mm/sec with a spacing of 1 mm is able to melt clay. Clay can easily absorb laser energy, which is due in part to its moisture content.

Wet clay [with less than 3% moisture content] is suitable for small-scale laser firing.

Using a multi-layered laser firing process, we created a ceramic ring. We used water cleaning methods to remove the ring from the surrounding material. Due to the effects of stress on the materials, the ceramic ring was not solid. This could be changed with improvements in 3D ceramic modeling.

The laser firing process creates results that are similar to those of the kiln reduction firing process. It also improves on the kiln firing process in several ways:

- 1) It allows for more precise control over oxidation and reduction firing areas on ceramics,
- 2) It requires a comparatively short firing time [the laser firing process is 99% faster than kiln firing],
- 3) There is no associated air pollution [100% reduction as compared to kiln firing],
- 4) It is possible to form a precise reduction firing area,
- 5) There are no expensive kiln costs [80% reduction in costs],
- 6) There is no complex training required to achieve reduction firing [99% less labor required as opposed to large-scale kiln firing].

A kiln takes over 22 hours to fire ceramic products. We can reduce the firing time to just 5 minutes by using laser firing.

4.1 Results

Variables of the laser firing process include 1) power, 2) speed, 3) focal length, 4) spacing and 5) volume of air flow.

1. The laser's speed setting is usually higher than the power setting. At slow speeds, the clay melts better than it does under a high-powered laser. High power settings cause clay molecules to swell too quickly. This causes a failed firing and a melting, magma-like ceramic. For this reason, we tend to use low power settings when firing ceramic.

A defocused laser causes the laser light to overlap on the ceramic surface. A lens focal length between 20~40mm causes low energy accumulation.

2. To maintain steady laser output, keep the laser lens clean, and prevent smoking, most laser machines have an air-blowing function. We controlled the air pressure levels in our study by creating a switch for the air-blowing tube, which is located next to the laser lens. We found that high air pressure blows away the liquid ceramic and forms an etched area.

With low air pressure, the liquid ceramic is able to stay on the ceramic surface. By controlling the air expelled by the laser, we can potentially achieve laser printing, cutting, firing, and surface treatment on craft ceramic.

3. Craft clay melts well when fired with a 20W laser at 10~2 mm/sec with a spacing of 1 mm. After using laser firing, it is easy to pick out the craft clay works by water cleaning the final product and surrounding materials.
4. The moisture content of fired clay absorbs a lot of the laser's energy. Water-heavy clay leads to small melting areas or complete failure to melt. On the other hand, a 20W laser with a speed of 10 mm/sec can create cracks when fired at glass. This is because the relatively high energy creates stress on the glass's surface. When laser power is decreased to 10W and the speed is set to 10 mm/sec, the laser can be used for glass cutting.
5. In this study, laser firing achieves results that are similar to those of kiln reduction firing. Using laser firing, we can make a ceramic surface on which oxidation and reduction finishes coexist on the same firing area.

Laser firing is also free of many of kiln firing's shortcomings. These include 1) long firing times, 2) large amounts of air pollution associated with reduction firing, 3) unpredictable reduction firing results on ceramic, 4) Expensive kiln costs, and 5) the need for a specialized workforce. Kilns also take more than 22 hours to fire a complete ceramic product. With laser firing, what once took hours now takes just a few minutes.

6. Most kiln-fired ceramics are non-conductive. Oxides are combined by covalent bonds, and with laser-firing, the covalent bonds become metal bonds. This means that laser firing can produce ceramic products that are superior in terms of light, heat, magnetism, and electricity.

4.2 Suggestions

In this study, we used 20W lasers to fire craft ceramic. These lasers are low-power and easily accessible. The materials we tested include 1) Taiwan Miaoli clay, 2) kaolin clay, 3) glass, 4) tiles, 5) glaze, and more.

We found that ceramics with large molecular gaps can withstand more laser heating stress.

The 20W Laser can be used to cut wood and fire ceramics.

As the 100W laser machine's price goes down, it is becoming more popular in primary schools in Taiwan. These lasers not only cut plywood but can also fire ceramic and be used in science education. With adequate course planning and teacher training, these lasers could be an interesting addition to primary school curriculum.

To complete ceramic firing in a kiln, you need over 22 hours. Throughout this energy-intensive process, only 3.5% of the energy in the kiln is directly used to fire the ceramic. On the other hand, laser firing can melt clay in less than 5 minutes without a kiln or other related equipment. The total cost of laser firing is more than 80% cheaper than kiln firing.

Using a 20W laser at 2~5 mm/sec, a 3% CuCO_3 glaze did not display a clear red color. When refired at 1 mm/sec, however, the glaze displayed a clear red color. We changed the glaze component to 100% CuCO_3 and fired it on a ceramic surface. With a 20W laser and a speed of 5 mm/sec, the ceramic displayed a red color and adequate melting.

The laser firing time is much shorter than the firing time needed for the reduction step in a kiln. The laser requires 1/72 the amount of time that the kiln does.

4.3 conclusions

Laser firing is a promising new ceramic firing technique. We have 25 years of experience with kiln firing, including kiln-building, kiln firing skills, and expertise on ceramic glazes. In Taiwan, we also published a paper about how to construct a kiln that will reduce energy waste, recycle heat, and reduce air pollution.

The following is a quick introduction:

“ We made changes to the kiln firing process in order to reduce heat waste and conserve heat energy. In our design plan, excess heat is used to heat the water circulation system, and the hot water is used in an artificial hot spring for power generation. In this way, we hope to promote the ceramic leisure industry and add to ceramic's industry value. Waste wood has many impurities, so choosing an absorbent that can absorb pollutants is important. Water is a good absorbent for many types of pollutants. In the flue, we installed a spray washing system to reduce ash pollution. This system sprays water into the chimney flue. In the flue, water droplets and exhaust gas trap ash particles in water droplets. With these water droplets, we use the diffusion mechanism and remove pollutants.”

Based on our observations, we believe that laser firing is a breakthrough innovation for craft ceramic production.

Cleaner production

Traditional kiln firing wastes over 75% of the energy involved in the firing process. It also requires worker training for specialized skills like process control and waste utilization. (Yi Huangac, Jiwen Luo, BinXiaa, 2013)

This inefficiency is enough to necessitate change in mainstream ceramic production methods. Laser firing poses none of the environmental or economic challenges that come with kiln firing. Laser firing can create the effect of reduced firing without the oxygen required for kiln firing. This makes laser firing a cleaner alternative for mainstream ceramic production.

Sustainability & Environmental concerns

Making conductive ceramics in a kiln is time-intensive. It requires cutting, welding, and gluing a piece of conductive ceramic to create a new piece with electrical function. Using laser-firing, we simply placed ceramic elements on different layers throughout the firing process. This created an electrically functional ceramic piece. In this way, laser firing reduces production costs and lessens the environmental impact associated with the reduction process.

Laser firing not only reduces kiln firing times and costs but also prevents air pollution. Via laser firing, we can get ceramic firing data quickly and cheaply.

Each ceramic element has its own firing traits, and these traits in turn change the glaze traits in the final ceramic piece. For this reason, we recommend that researchers continue exploring laser firing techniques.

5. References

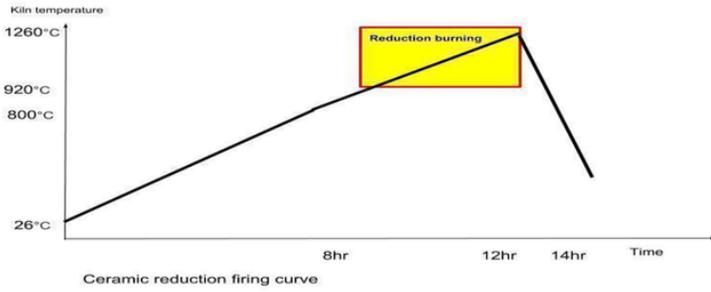
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6. Tables

Due to technical limitations, tables are only available as a download in the Supplemental Files section.

Figures



A) Ceramic reduction firing curve



B).Copper glaze artworks with reduction firing. [red]



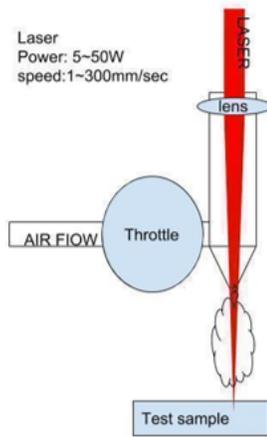
C)copper glaze artworks with oxidation firing. [green]

Item	Input%	Output%
Fuel combustion heat + sensible heat + kiln heat storage	100	
clay crystal water + absorption water + evaporation heat		0.55
Burning heat of clay body		2.91
Heating Kiln Heat		3.12
Kiln body heat storage		18.67
Exhaust Sensible Heat		45.9
Heat loss from incomplete combustion		16.24
Radiated Conduction and Other Loss of Heat		12.61

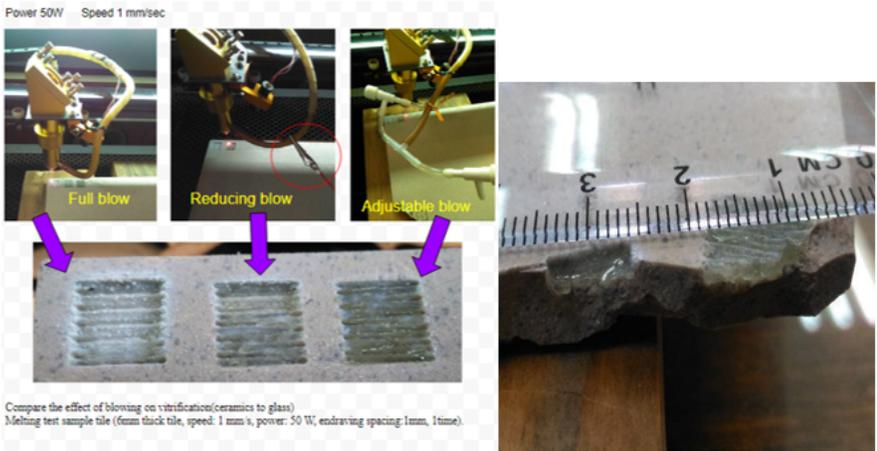
D) Kiln firing thermal efficiency

Figure 1

A) Ceramic reduction firing curve , B) copper red glaze artworks [red] , C)copper green glaze artworks [green]. D) Kiln firing thermal efficiency



A) Sample setting



B) Laser refit



Welding test

Figure 2

A) Sample setting, B) Laser refit, Comparing vitrification (ceramics to glass) results with different air blowing on the ceramic surface, and C) Welding test. Test sample: tile (6mm thick, speed: 1 mm/s, power: 50 W, engraving spacing: 1 mm, 1 time).

$$\text{Power Density} \left(\frac{W}{\text{cm}^2} \right) = \frac{250}{d^2} \times \text{Power}$$

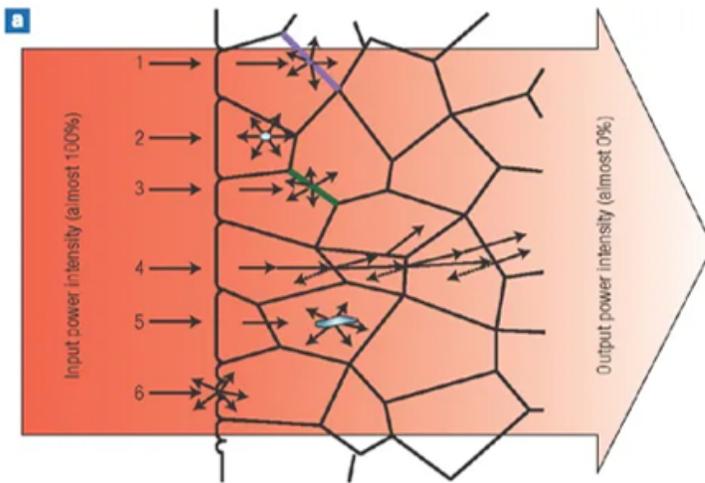
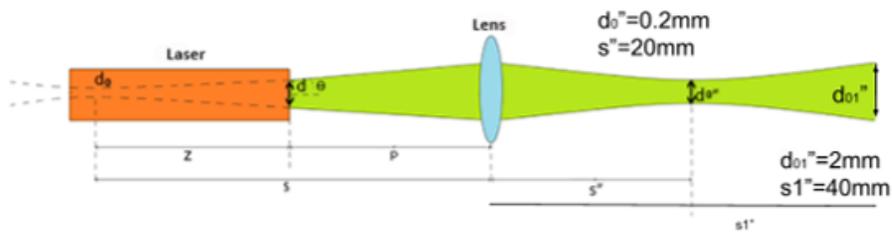
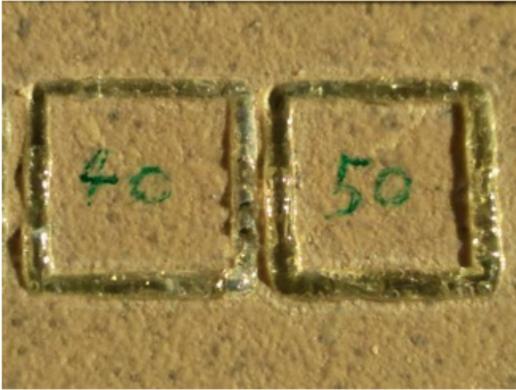


Figure 3

The formula, measurement results, laser light point, and the microstructure of conventional and advanced transparent ceramics. (Akio Ikesue, Yan Lin Aung, 2008)



a) Laser cutting test. Laser: (10W~50W, 1mm/sec), Sample: 6mm thick tiles



b) Laser 3D Clay printing test, steps: 1) Laser used to process multiple levels of clay, 2) Clay cleaned with water, 3) Final sample.

Figure 4

Material and production test. a) Laser cutting test. Laser: (10W~50W, 1mm/sec); Sample: 6mm thick tiles. b) Laser 3D Clay printing test. Steps: 1) Laser used to process multiple levels of clay, 2) Clay cleaned with water, 3) Final sample.

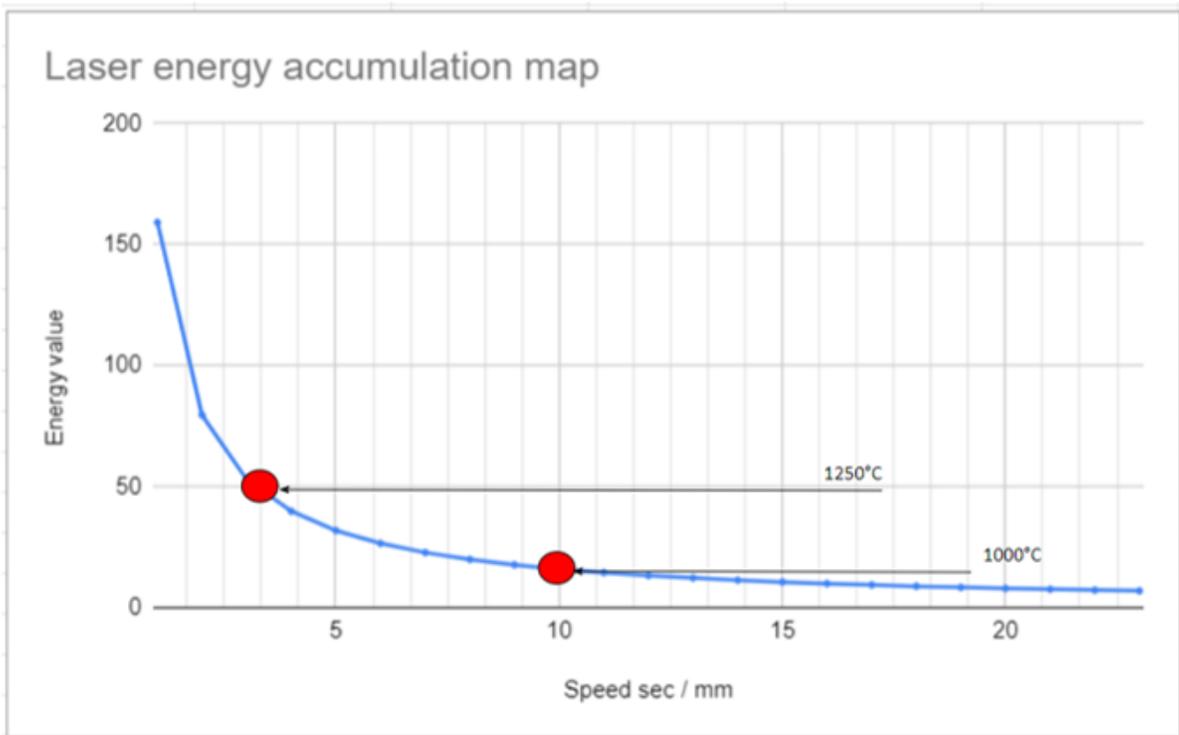


Figure 5

Comparative map of ceramic melting point, laser firing energy, and kiln firing temperature.

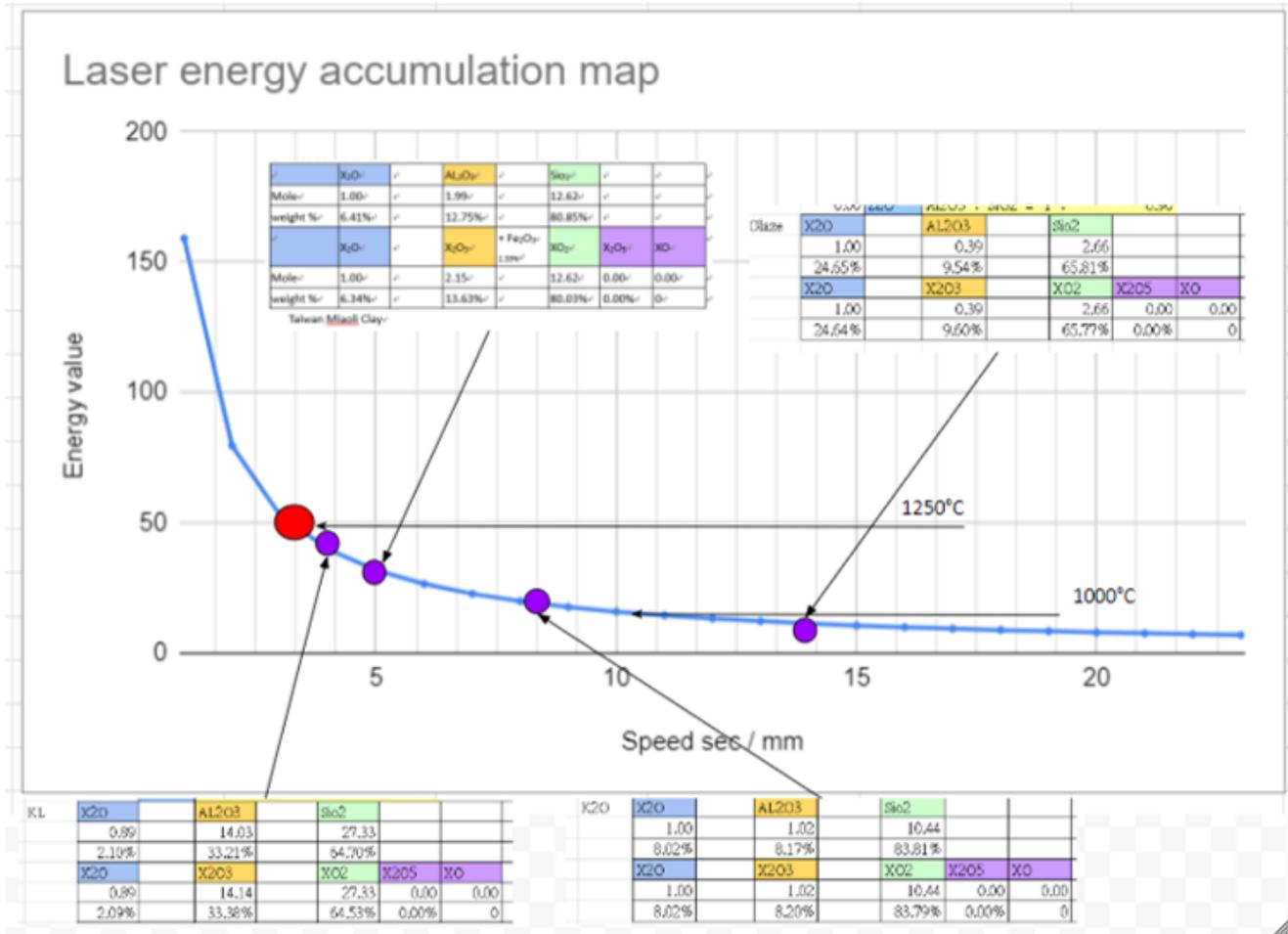


Figure 6

Laser-firing energy map comparing ceramic melting temperatures with different kiln-fired glaze formulas.

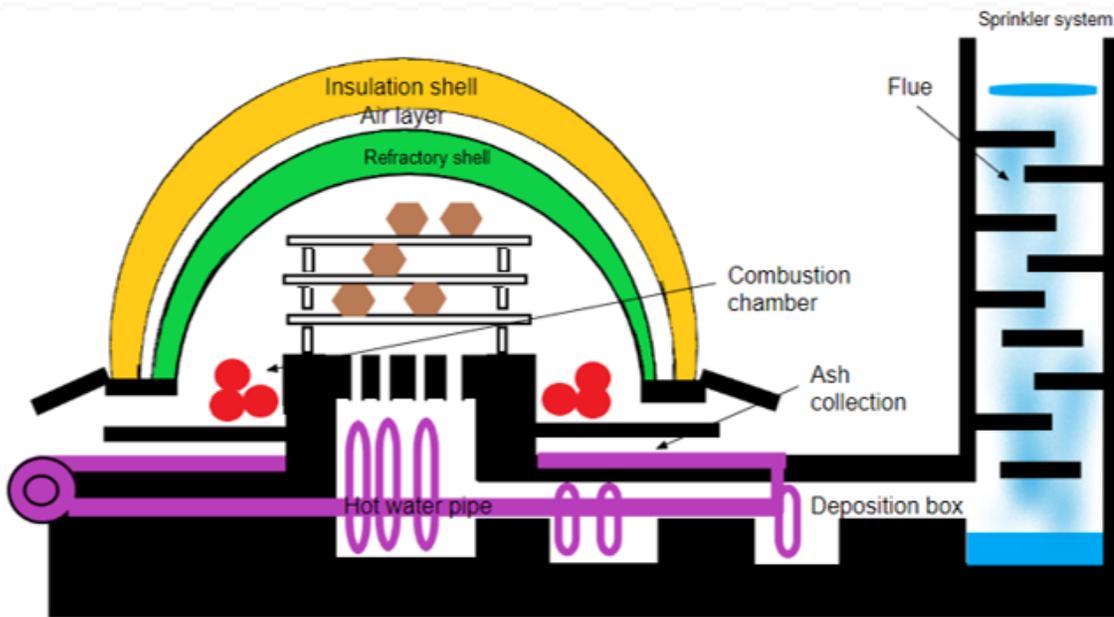


Figure 7

Wood fire kiln Redesign [Jay Lee No. 1]

Supplementary Files

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- [table.docx](#)