APPLICATION OF LASER TECHNOLOGY TO CERAMIC DESIGN

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ABSTRACT

Spanish ceramic products must have a high added value in design to compete in an increasingly global market.

In recent years, laser technology has been applied in numerous processes, such as welding, marking, cutting, etc., offering a high degree of flexibility, safety and accuracy. Thus, in many production sectors, it has replaced traditional processes.

However, laser technology has not been studied in depth in the field of ceramic decoration. The only reference point has been the firm ESMALTES, S.A., which was awarded the "Alfa de Oro" Prize at the Cevisama 2003 trade fair for laser engraving of ceramic tiles.

The present paper sets out the results obtained in the project entitled "Application of laser technology in the development of decorating techniques", *funded by IMPIVA through the European Social Fund.*

The following processes have been studied in the frame of the project:

- *Underglaze decoration, without altering the properties of the glaze layer.*
- *Selective firing of a glaze or third-fire decoration.*
- *Addition to the glaze of laser radiation sensitive inorganic compounds.*

The optimum laser parameters have been established for each of these processes.

1. INTRODUCTION

The term LASER is an acronym of: Light Amplification by Stimulated Emission of Radiation, which could be translated into Spanish as "amplificación de luz mediante la emisión estimulada de radiación".

Lasers are sources of light, for instance, just like incandescence lamps, but laser light displays a series of properties which distinguish it from other types of light. Laser light is a monochrome, coherent radiation (the waves or photons propagate in phase), which is very intense and directional (it does not broaden)[1-2].

1.1. LASER PARTS

A laser consists of an active medium capable of producing radiation, an external energy source, the most usual being of the optical or electric type, a resonance cavity or box that contains the active medium, and two parallel mirrors. One of the mirrors is almost 100% reflectant, while the other has around 90% reflectance (Figure 1).

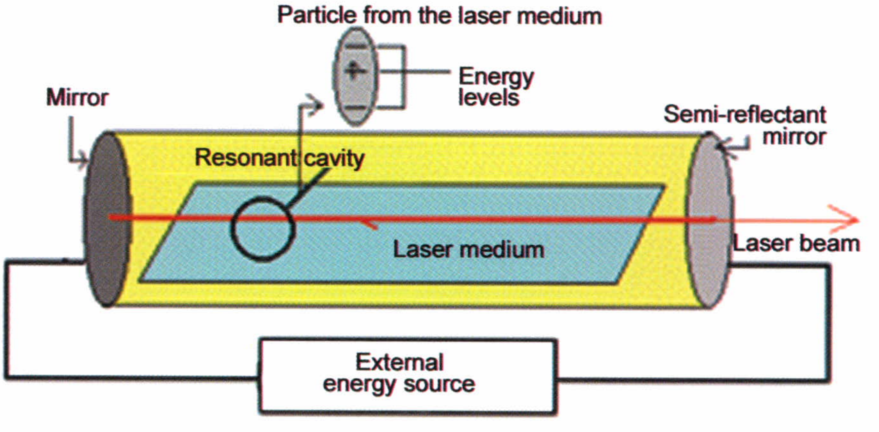

Figure 1. Laser parts[3].

1.2. LASER OPERATION

The external energy source contributes the necessary energy for the particles (atoms, molecules or ions) in the active medium to go from their basic state to an excited state of higher energy.

The photons emitted spontaneously are reflected in mirrors and repeatedly cross the active medium. When one of these photons strikes an excited particle, this produces an instantaneous de-excitation of this particle by the emission of a photon, in phase with the first and having the same energy. This phenomenon is termed stimulated emission.

Only the photon, which moves in the direction defined by the optical axis of the resonator, will be amplified by the stimulated emission process, immediately generating an enormous flow of photons that propagates along the optical axis of the resonator.

The light fraction transmitted by the mirror, which has a reflectance of 90%, constitutes the operative laser beam.

1.3. TYPES OF LASERS

A great variety of lasers is found of different sizes, configurations and properties[1]. One possible classification is based on the nature of the active medium, which can be a solid, a liquid or a gas. Thus, we can speak of:

- Solid-state lasers, such as Nd:YAG, ruby or titanium-sapphire lasers.
- Liquid lasers, such as the rhodamine laser.
- Semiconductor lasers, such as the gallium arsenide laser.
- Gas lasers, such as the He-Ne, CO_2 or Ar lasers.

1.4. LASER APPLICATIONS

Potential laser uses are almost unbounded due to their versatility. Lasers have become very valuable tools in industry, scientific research, telecommunications, military technology, medicine and art.

Thus, lasers are used in operations such as eye surgery, synthesis of new materials, guided missile systems, high-density information storage systems, etc.

2. APPARATUS AND EQUIPMENT

A FOBA FD84S laser, installed at the ALICER laboratories, has been used. This instrument consists of the following parts:

- Transverse diode-pumped Nd:YAG laser head, 1064 nm, of 50 W.
- Scanning system, mounted on the laser head, with standard lens, marking area 114x114 mm.
- ILS 100 pointer.
- Control cabinet, which includes a computer, power source and water/air cooler, independent of external cooling water.
- FOBAGRAF user software.

For the installation of the ceramic pieces, a 640x800 mm bench was available, made up of aluminium profiles with a motorized, height-adjustable supporting frame.

3. THEORETICAL FUNDAMENTALS

3.1. OPERATING MODES

There are two types of laser in terms of operating mode: continuous and pulsed lasers. In the continuous mode, the laser emits radiation in a continuous form, whereas in the pulsed mode, the laser emits energy in the form of pulses. The difference between both modes is the duration of laser emission.

3.2. LASER PARAMETERS

In continuous lasers, mean power is involved, whereas in pulsed lasers the pulsing power is equal to the ratio of its mean power to the product of pulse width by repetition frequency.

Pulse power and laser radiation displacement velocity are the most important parameters from a materials processing point of view.

4. RESULTS AND DISCUSSION

Ceramic materials (wall and floor tiles) are poor conductors of heat and are affected by the high energy density of laser radiation[4]. The thermal gradient between the laser incidence area and the rest of the piece gives rise to stresses in the glassy phase. These stresses can lead to cracks and even failure of the ceramic piece (Figure 2).

Phase changes also need to be considered, as a result of the thermal shock produced by the laser beam. These phase changes cause relatively large stresses in the ceramic material, because they are accompanied by local volume changes.

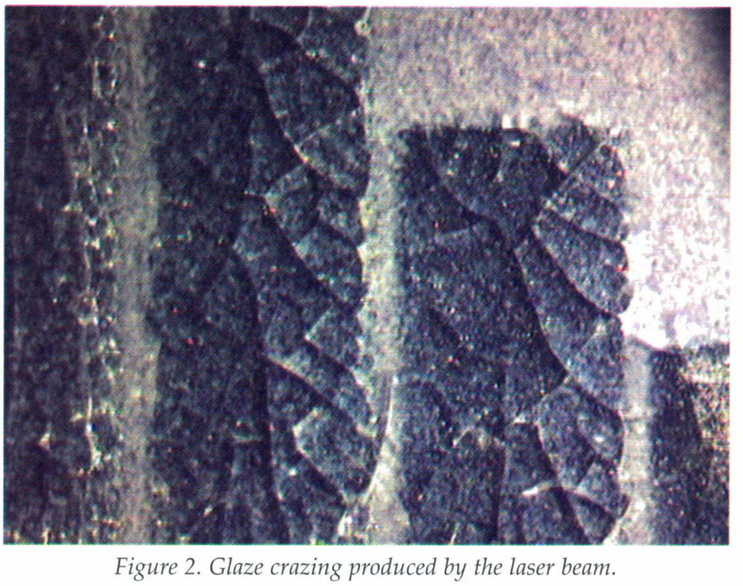

Figure 2. Glaze crazing produced by the laser beam.

The formation of these stresses occurs because during rapid cooling, due to the low heat conductivity of the glassy phase, thermal dissipation does not take place at the same rate throughout all the mass, but a temperature gradient is established from the laser beam incidence region towards the rest of the piece. The most distant regions, which cool more quickly, become rigid and shrink before the nearest ones, which are still hot and in a plastic state. As the thermal gradient disappears, these also shrink, but can no longer do so freely, because they encounter the opposition of already rigid regions, which prevent these other regions from reaching dimensional equilibrium, on cooling, in accordance with their coefficient of expansion[5].

One possible solution for eliminating such stresses would be by heating the piece in a kiln, as a preliminary step prior to the laser process. This preheating would minimise thermal shock, cancelling the gradient originated by the laser beam and facilitating the structural relaxation of the glassy phase by viscous flow.

However, such heating would complicate the process from an industrial point of view, so that it was decided to decrease the thermal gradient by optimizing the following laser parameters:

- Focal length
- Pulse frequency
- Beam power
- Rate of advance

Table 1 details the values of the laser parameters, which allow optimum processing without altering the original properties of the glaze.

Frequency (kHz)	Focal distance (mm)	Diaphragm (mm)	Rate of advance (mm/s)	Intensity (A)	Line separation (mm)
12-15	207	2	100	25-30	0.02

Table 1. Optimum values of the laser parameters for ceramic materials processing.

The frequency, given in kHz, indicates the number of pulses that reach the piece per second.

The rate of advance, in mm/s, regulates the amount of heat contributed. It has been attempted to give it the highest possible value without losing definition, since this reduces the heat input and increases productivity.

The diaphragm is a circular opening that regulates laser radiation energy density. The greatest energy density is obtained with diameters between 1.5 and 2.5 mm.

Diode current intensity is directly proportional to laser beam energy. The greater the current intensity, the greater is the laser radiation energy.

Figure 3 shows the surface of a glaze after laser processing using the parameters given in Table 1. As may be observed, the glaze exhibits no cracks.

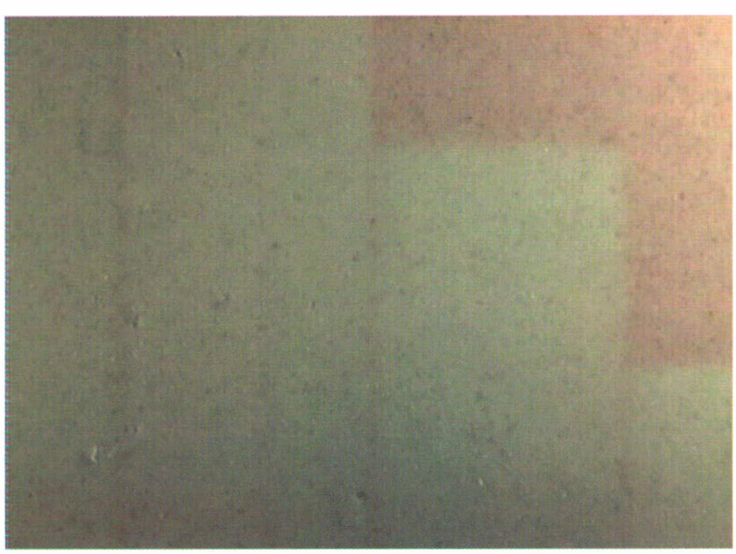

Figure 3. Laser processing of a glaze, using the values given in Table 1.

4.1. UNDERGLAZE DECORATION

Lasers have been shown to cause a change of colour in some inorganic pigments used in glaze colouring[6-7].

These changes in colour or contrasts can be used to produce designs with decorative applications. This type of decoration is possible, since the glaze is transparent to the Nd:YAG wavelength.

What is sought is not ablation or scoring, but a decorative effect that does not alter the properties of the glaze layer (smooth texture, impermeability and resistance).

Varying the laser focus enables designing an in-depth image. This effect is more pronounced when the glaze layer is thicker.

The advantages with regard to traditional techniques are:

- There is no mechanical contact between the laser beam and the object to be decorated, so there is therefore no tool wear and maintenance is minimal.
- Possibility of developing complex designs, which would be impossible to make with any other currently implemented decorating system, since the laser is a very narrow beam of light with no scatter.
- Rapidity in processing.
- Variety and easy changeover.
- High repetitivity.
- Fully automated.

Figures 4-6 depict some examples of underglaze laser decoration.

Figure 4. Decoration of a glaze. Design resolution: 1270 dots/inch.

Figure 5. Decoration of the engobe layer. The depth effect is more pronounced with increasing glaze layer thickness. Design resolution: 1270 dots/inch.

Figure 6. Decoration using grits. A greater depth effect can be achieved using transparent grits. Design resolution: 1270 dots/inch.

4.2. ADDITION TO THE GLAZE OF LASER RADIATION SENSITIVE INORGANIC COMPOUNDS

Glass is transparent to Nd:YAG laser radiation. However, incorporating additions into the glaze enables obtaining a glaze that is opaque to the Nd:YAG emission wavelength (1.06 μm). This radiation absorption causes a change of colour in the zones where the laser strikes.

From these changes of colour or contrasts, designs can be made with decorative applications.

In addition to these decorative applications, other possible applications can be derived:

- Identification of the manufacturer with the end product.
- Classification and later file of trims, particularly in the third-fire sector, where the pieces have a very short commercial "life".

At the present time, the ALICER Development Department is working on a laser radiation sensitive inorganic compound. This compound is resistant to firing and colourless. In addition, it does not modify the properties of the glaze because it is added to the composition in a very low concentration.

Laser radiation causes a change of colour in those areas of the piece where it strikes, since this product absorbs laser radiation and changes colour, producing a contrast (mark).

It is possible to make a very small size mark, which is visually imperceptible, in order to identify a piece, and as the mark is tiny, very high marking rates can be achieved.

Figure 7 shows a mark of 10 mm.

Figure 7. Mark of 10 mm diameter. Resolution: 1270 dots/inch.

4.3. SELECTIVE FIRING OF A GLAZE OR THIRD-FIRE DECORATION

Another point of interest in laser technology is selective firing of an ink that has previously been deposited on the ceramic piece. Ink firing only takes place in those areas where laser radiation is applied[8]. This process is known as third-fire decoration (Figure 8).

The first trials have shown that ink layer thickness is an important factor to be taken into account. A thin layer absorbs an insufficient amount of radiation for ink firing to occur. What is observed is ink expulsion as a result of the impact of the laser waves.

This decoration can be made on a ceramic tile or glass. Although ink melting temperature (1100ºC) is much higher than that of glass, the decoration is possible because the interaction of the laser with the glass is only a few microns.

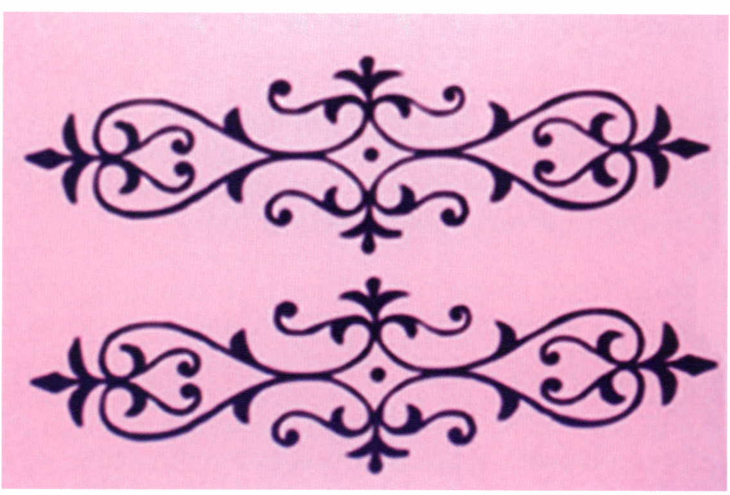

Figure 8. Decoration by laser firing of an ink.

5. CONCLUSIONS

Lasers are tools that can be used in the field of ceramic decoration. The Nd:YAG laser enables performing in-depth underglaze decoration, since the glaze is transparent to the wavelength of this laser. Some ceramic pigments are sensitive to laser radiation and give rise to contrasts or marks. Using this contrast, it is possible to make designs with decorative applications.

Adding certain inorganic non-colouring compounds to the glaze, which are sensitive to laser radiation, allows marking each ceramic tile for identification purposes, for greater control in storage, distribution, sales and even building stages. The high laser resolution enables making very small size marks that are visually imperceptible.

As an energy source, lasers can be used for selective firing of a glaze or an ink. Firing only occurs in those areas where laser radiation is applied.

Finally, to conclude, lasers may be considered very versatile tools that will enable performing different applications in the ceramic sector in the near future, as has been the case in other industrial sectors.

6. ACKNOWLEDGEMENTS

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