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Experimental study on laser marking of alumina

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Abstract

Alumina is one of the most employed ceramics in industry because of its good properties. Components made of alumina are essentially identified by a code or a symbol printed directly on them. However, there is still a lack of a reliable and efficient method to mark alumina. Particularly, laser typically produces marks with poor contrast.

In this work, an extensive experimental study on laser marking of alumina was carried out with the aim of finding out the optimal parameters to produce high contrast marks. Four different lasers working at three different wavelengths (infrared, visible and ultraviolet) were employed for the treatments. Colorimetric analyses were carried out in order to have an objective and quantitative comparison among marks and resulting contrast. The optimum operating conditions of the laser marking process were determined.

Keywords: laser marking, alumina.

1. Introduction

Alumina is a widely employed material in industry mainly because of its good characteristics besides its relatively low cost. High electric and thermal insulating capacities are among its excellent features.

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Moreover, its good mechanical behavior makes it suitable for some applications requiring high wear resistance and hardness.

Components made of alumina need frequently to be identified by a code printed directly on them. For example, some electrical components must have a code related with their main characteristics. In this sense, laser marking is a well-known process for industry because of its versatility, speed, etc. Moreover, there is no need of using inks, which is an essential aspect in certain applications as in the medical industry.

In spite of that broad industrial implementation, laser marking of ceramics (and more specifically alumina) has a problem: the obtained marks have a very low contrast, so they cannot be easily seen. Actually, pure monocrystalline alumina at ambient temperature is transparent to visible light and to laser radiation from near-infrared to near-ultraviolet (Apetz and van Bruggen, 2003). Its typical white appearance is due to light dispersion at the grain boundaries of polycrystalline alumina. Particularly, oxygen vacancies are the most likely defects in alumina. They are also known as F-centers or color centers because they produce electromagnetic radiation absorption bands in the spectrum region in which they do not normally absorb (Perevalov et al., 2010) which means that they produce indeed coloration on alumina. The physical mechanism involved in the coloration of alumina by near infrared lasers has been already reported (Penide et al., 2015). Laser heats alumina, which in turn produces thermal desorption of oxygen atoms (vacancies) so F-centers are produced. On the other hand (Pedraza et al., 1994) stated the mechanism of producing coloration by UV lasers. It is also produced by generation of oxygen vacancies (F-centers) but in this case, this desorption is not produced by heating of alumina but by ablation of oxygen atoms. Therefore, the contrast of the mark can be really improved by performing the laser treatment in inert atmosphere because the oxygen vacancies are not filled again by atmospheric oxygen atoms, so more F-centers are produced. Therefore, the physical mechanism of marking alumina by laser is already well stated.

The aim of this work is to compare the results of laser marking of alumina by three different wavelengths: infrared, visible and ultraviolet. Colorimetric analyses were performed in order to state the contrast of the different marks.

2. Materials and methods

All marking experiments were carried out on high purity alumina (97.5 %) plates.

Laser treatments were made by three diode end-pumped Nd:YVO_4 lasers (Powerline E 20,Rofin-Sinar) emitting in its fundamental wavelength (1064 nm), second (532 nm) and third harmonic (355 nm) respectively. The first one was set to work in continuous wave with a power of 7 W and in pulsed mode in the other two sources with 4.3 and 1.35 W of average power respectively and at a frequency of 20 kHz. These lasers have galvanometric mirrors in order to scan the surface of the sample with a speed of 25 mm/s and 1, 10 and 50 laser passes for each treatment in order to counteract the difference in power between lasers. Marking experiments were also carried out by a monomode Ytterbium-doped fiber laser (SPI, SP-200) emitting in continuous wave (1075 nm) with a power of 200 W and 300 mm/s of speed. Laser treatments were made with a flow of argon right over the surface of the alumina since it was demonstrated to be the best choice (Pedraza et al., 1994; Penide et al., 2015).

We have taken images by an optical microscope of the treatments made by each laser. On the other hand, we carried out some colorimetric analyses so as to have an objective and reliable comparison of the different contrasts produced by the different laser treatments. The alumina plates were illuminated at 45º incidence using a white light fluorescent tube lamp (OSRAM L 13W/21-840). The spectrum of the reflected light was sampled with a spectroradiometer (PR-650 Spectra Scan). This device measures the wavelength range 380–780 nm at 4 nm steps. Therefore, we obtained the spectrum of the light reflected by the surface and the tristimulus values CIEXYZ of its color. These data were averaged over five different measurements for each sample. Our comparison is based on the analysis in one of the tristimulus values: the luminance ("Y" value). Luminance is an indicator of the brightness of a surface: higher luminance values correspond to bright surfaces, such as untreated alumina, whereas lower values correspond to dark surfaces, such as well-marked alumina.

3. Results and discussion

Table 1 summarizes the results of the colorimetric study as well as the laser processing parameters employed in each case.

Table 1. Most important laser processing parameters and resulting luminance value of each laser treatment and untreated alumina.

Sample/laser	Power (W)	Speed (mm/s)	Passes	Luminance (cd/m^2)
Nd:YVO_4 laser UV	1.35	25	50	440.40
Nd:YVO_4 laser green	4.3	25	10	293.60
Nd:YVO_4 laser IR	13	25	1	240.40
Fiber laser IR	200	300	1	76.07
Untreated alumina	-	-	-	516.70

Untreated alumina is naturally white because of its grain boundaries (Apetz and van Bruggen, 2003), so we have already expected that its luminance value is high since it has a light surface. On the other hand, all the laser treatments produce darkening of alumina, so their luminance is lower.

All these lasers are able to produce marks in alumina, but not all of them with the same effectiveness. Treatment made by the ultraviolet Nd:YVO_4 laser showed the highest luminance, meaning that this treatment produces the lowest contrast with the untreated alumina. In figure 1, we show an image of this treatment. A square mark can be seen, but it does not show a good contrast with untreated alumina. This kind of laser has an output power that seems clearly insufficient to achieve a good mark. Moreover, laser treatment has removed some of the alumina from the surface, so the energy of the laser beam is not only employed to produce oxygen vacancies but also to produce ablation of alumina.

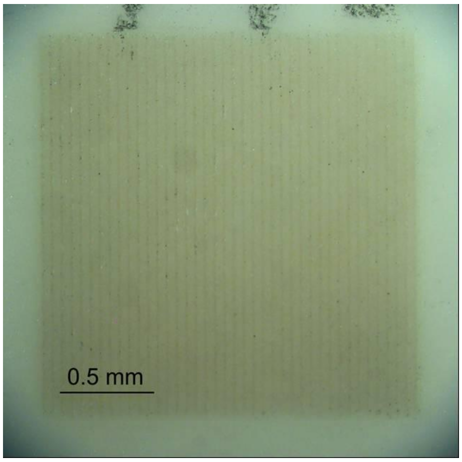

Fig 1. Optical image of a treatment by the ultraviolet source of the Nd:YVO_4 laser.

Regarding the green laser treatment, the color is darker than the one obtained with the UV laser. This laser has a higher output power than UV laser, but it seems that also the wavelength is more convenient to mark alumina. In figure 2, it can be seen that the laser treatment produces a particular texture in alumina. It seems that this wavelength is capable of producing ablation of alumina as well. But regarding the coloration, the color is darker than the one made by UV laser, therefore the green source of Nd:YVO_4 laser produces a higher quantity of oxygen vacancies. This is probably a consequence of the high peak output power delivered by the Q-switch mode of this laser, which produces easily ablation of this material.

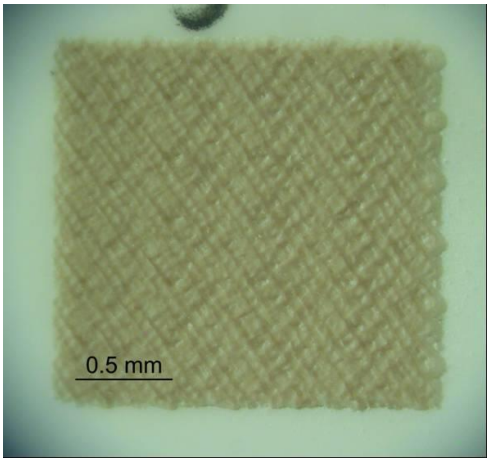

Fig 2. Optical image of a treatment made by the green source of the Nd:YVO_4 laser.

IR Nd:YVO_4 laser produces a slightly darker mark (lower luminance value). However, in this case the actual difference is in the texture of the treated surface. Figure 3 shows that this laser treatment does not produce ablation of material. Alternatively, it heated and melted alumina since the surface is clearly resolidified.

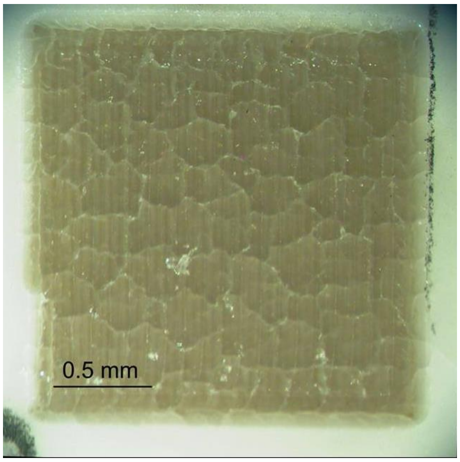

Fig 3. Optical image of a treatment made by the infrared source of the Nd:YVO_4 laser.

Finally, the data on table 1 demonstrates that the darkest mark (lowest luminance value) was made by the fiber laser. In figure 4, an image of the treatment made by the fiber laser can be seen. It is clear that this laser produces a higher quantity of oxygen vacancies. It can also be observed that alumina was clearly melted as well. Of course, the darkest mark is also related to the higher power delivered by fiber laser.

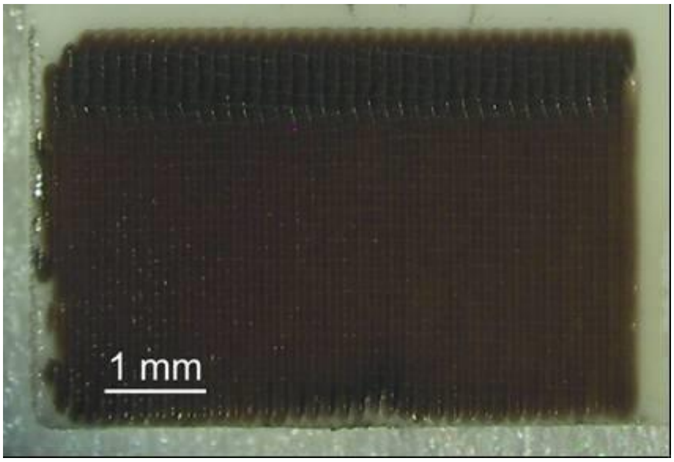

Fig 4. Optical image of a treatment made by the fiber laser.

4. Conclusions

Fiber laser was demonstrated to be the most effective to produce high contrast marks in alumina among the four lasers under study. Every laser studied in this work is able to produce a mark in alumina, however, the colorimetric analysis and the optical microscope images state that the darkest marks are produced by fiber laser.

In the case of UV and green lasers, they produce coloration in alumina, but also ablation of material. It is probably because in spite of the low output average laser power that these lasers deliver, their high peak power leads to high ablation rates. Among them, the green is the one that seems to produce the darkest marks.

Regarding the IR lasers, fiber laser is clearly the one that generates the best marks. They both deliver a continuous wave radiation which, combined with their wavelength, avoids any ablation. Instead of that, they heat the surface of the alumina plate, which leads to thermal desorption of oxygen. Finally, fiber laser is the one that should be choosen for generating higher contrast marks. It is probably because of its clearly higher average laser power.

Acknowledgements

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