Laser Technology for the Rapid Repair of Defects in Sanitary Ware: Prospects and Challenges


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The repair of defects in sanitary ware during production entails considerable costs to the process, requiring, in most cases, a second firing of the entire piece. Thus, the development of a solution based on the localized repair of faults is very attractive to the sector. Laser technology fulfills this requirement, with a highly localized heat source allowing the repair of small defects by a fast, economical and environmentally friendly approach. This work studied the interaction between a CO₂ laser and the glaze material to be repaired, setting the basic parameters to repair defects in sanitary ware pieces. This approach could decrease repair time from the 22 hours (conventional process) to only 7 min. However, due to the high thermal stresses, several cracks appeared in the ceramic surface being necessary an additional heat source, an infra-red lamp, to overcome crack formation. This combination reduced significantly the number of cracks and their dimensions. Nevertheless, a full functional solution was not possible to develop for sanitary ware, due to persisting thermal stresses issues.

Keywords: Laser processing; Sanitary ware; Defects repair; Glaze; Ceramics.

1. Introduction

The ceramic industry is under constant evolution, leading to significant improvements in automation and process efficiency. An area where considerable developments can still be made is in the treatment of small defects arising from manufacturing processes, which usually requires another firing to repair defects, even if they have only a few mm² in size. Roughly 30% of all the production needs to be repaired, which represents a significant cost associated with energy consumption, leading to high CO₂ emissions, less kiln available space for new pieces, and more manpower and time. One option is the use of laser technology for in situ repair of defects in the ceramic pieces, preventing all the extra costs associated with a re-firing of the whole piece in a kiln. According to the literature, the standard wavelength of CO₂ lasers (10.6 μm) is strongly absorbed by ceramic materials [1], allowing the repairs to be processed in a rapid and highly localized manner.

The application of laser technology in materials science is wide and versatile, with applications in welding, cutting and drilling, among others [2-6]. Focusing on ceramic materials, this technology has been reported for structural ceramic machining [7], surface treatment [8] sintering [9], growing of single crystals [10, 11] and texturing [12]. However, due to its highly localized heat source, the laser tends to produce thermal stresses leading to the formation of cracks [9]. Different approaches have been tested to overcome this issue, namely by the application of a heat source. For example, Hagedorn et al. preheated their sample to temperatures close to material’s melting point, before further sintering Al₂O₃-ZrO₂ ceramics without cracks, via selective laser melting technique [13].

In this work, a CO₂ laser irradiation was used to repair small surface defects on glazed sanitary ware ceramics. To avoid the formation of micro-cracks associated with thermal stresses, a diffuse heat source was used in the form of an infra-red (IR) light. The glaze used to repair the defects was characterized by hot stage microscopy, X-ray fluorescence (XRF), thermogravimetric/differential thermal analysis (TG/DTA) and laser diffraction particle sizing (COULTER). The quality of the repaired defects was visually assessed, highlighting cracks with methylene blue.

2. Experimental details

The sanitary pieces and the repair glaze were provided by Sanindusa S.A. The defects were simulated in the laboratory with the help of a drill, being roughly 3 mm in diameter and 0.5 mm in depth. The laser beam of a continuous CO₂ laser (200 W Spectron, model SLC) irradiated the sample with a spot size of ~4 mm in diameter, adjustable by using a ZnSe lens of 63.5 mm focal distance. The treatment cycles used are presented in Table 1 and 2. The thermal stability of the repair glaze was assessed by heating microscopy using a Leitz, model 2A set-up. The samples were uniaxially pressed into a 3 mm² cube using a special mold. The heating rate was 5 °C/min until a maximum temperature of 1220 °C. The chemical composition of the glaze was obtained by X-ray fluorescence (XRF) in a Philips X’Pert PRO MPD spectrometer. The loss on ignition (LOI) at 1000 °C was also determined. The thermal behavior of the sieved (<20 μm) powders was assessed by thermogravimetric/differential thermal analysis (TG/DTA) using a Netzsch STA409P apparatus. The heating rate was 5 °C/min, from room temperature to 1150 °C.
3. Results and discussion

Repairs were carried out with the glaze also employed in the conventional approach. This glaze is composed (wt.%) of SiO₂ (55.6%), Al₂O₃ (9.9%), CaO (8.6%), and in percentages equal to or lower than 5%: K₂O, Zr, Ba, Zn, Co, Na₂O (LOI of 5.8%). The powder average size is around 3.03 µm (D90 = 7.97 µm).

The glaze fusibility was assessed by hot stage microscopy, as shown in Figure 1 (top). Until 1125 °C the glaze shows no significant changes in sample shape and dimensions, indicative of its superior thermal stability. Indeed, the glaze starts to melt at around 1220 °C, verified by the change in the sample shape, which becomes progressively spherical. The thermogravimetric analysis of the glaze presents a total weight loss of 8.6%, with two well-defined steps at 520 °C and between 700-850 °C, as presented in Figure 1 (bottom). Both weight losses are ascribed to the decomposition of the glaze components. This assumption is validated by the presence of two endothermic peaks in the DTA, at the same temperature intervals. The weight loss noted at 520 °C is attributed to the dehydroxylation of the kaolinite to produce metakaolinite [14]. The weight loss between 700-850 °C can be ascribed to the decomposition of calcium and barium carbonates [15]. The defects were simulated with a drill and then repaired following an approach similar to that used by the industry. The holes were filled with a mixture of carboxymethyl cellulose (CMC) and glaze in a weight proportion of 1:3, but instead of a long kiln cycle (~22 hours), a CO₂ laser was used to sinter the repair glaze (Figure 2a). The laser treatment cycle was optimized taking into account the laser power and the irradiation time, presenting the best results using a shorter cycle, around 7 minutes (Table 1). The defect depth induced by laser interaction is presented in Figure 2b-d. Laser promotes the melting of the glaze, with a complete bond between repaired glaze and the surrounding areas, while the edges of the defect become undetectable at naked eye. Nevertheless, cracks appeared, as result of thermal stresses. Besides the formation of cracks running across the repaired area, a significant circular crack, roughly 1.5 mm around the area of laser interaction, is also visible. This defect was found to be extensive, reaching the ceramic body beneath the glaze. Indeed, sample’s cross-sections show the delimitations of the laser treatment. Additionally, it was noted that the laser treatment presented a lower defect depth compared to the traditional kiln firing technique.

![Figure 1. Glaze characterization: heating microscopy photographs (top) and TG/DTA curves (bottom).](image)

![Figure 2. Scheme of the laser treatment, D=13 cm (a). Samples repaired using only the laser (75 W) in defects with depths of 0.5 mm (b), 0.8 mm (c), and 1 mm (d).](image)

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Table 1. Cycle, time and laser power, used to repair defects in Figure 2.
found that for defects depths deeper than 0.5 mm, the laser is not able to melt the repaired material, as can be observed in Figure 2.

The cracks created by the thermal stresses were addressed by applying a diffuse heat source, namely an infrared (IR) lamp, capable of reaching temperatures ∼700 °C (Figure 3a). The samples repaired combining laser and IR heat sources under the conditions presented in Table 2, are shown in Figure 3b-d. The distance between lamp and sample appears paramount to the ability to remove the circular crack, as proven by comparing sample b (2 cm) with samples c and d (1 cm). The defect cross-section also validates this assumption, with sample b showing a crack that promotes a clear separation between the repair material and the sample glaze, highlighted by the methylene blue, compared with a crack-free repaired defect in samples c and d. The increase in laser power, from 38 W (sample c) to 43 W (sample d) leads to the appearance of a transparent area, due to the material’s vitrification.

Samples with undetectable transitions between the repaired areas and the surrounding glaze, when observed from the top and in cross-section views, were obtained, supporting the applicability of this technology in small pieces and defects. Nevertheless, the conditions tested in this approach were unable to prevent, in real sanitary ware, cracks formation induced by thermal stress cracks. However, it is important to emphasize that they do not possess the size and extension of the cracks presented without the IR lamp. The thermal resistance differences observed when applying the same repairing procedure to samples with approximately 7.5 cm² and to sanitary ware pieces can be ascribed to the geometric complexity of the latter ones. Their complex forms, with curvatures, differences in thickness and sharp edges leads to a non-uniform heat dispersion leading to the formation of thermal stresses that induce their collapse. The smaller size and simpler symmetry of the sample pieces (7.5 cm²) makes them resistant to thermal shock. A possible approach to overcome this problem is the homogeneous heating of the entire sanitary ware piece, e.g. in an oven. Obviously, a specific set-up will be required to allow the interaction between the laser beam and the sanitary ware pieces inside the oven, at a relatively high temperature. Thus, the application of this approach in real sanitary ware for industrial application still requires further optimization.

4. Conclusions

The use of the laser technology to repair small defects in sanitary ware showed good prospects. The laser was able to melt the traditional repair glaze to depths of 0.5 mm, producing a uniform and strong bonding between the repaired area and the glaze surrounding it. Nevertheless, the thermal stresses caused by the extreme and localized heating led to the appearance of several cracks, noting a deep circular crack with 1.5 mm around the defects. In an attempt to overcome this issue, an infrared lamp was used as a diffuse heat source. This approach significantly reduced the number and severity of the stress cracks. Furthermore, the large circular crack around the defect was also eliminated.

Unfortunately, a repaired defect in real pieces with similar characteristics to the traditional approach was not yet achieved, with some issues regarding thermal stresses still remaining. However, there are excellent prospects that this approach can
bring significant gains in terms of production time, cost and environmental savings, after further optimization.

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