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CO_2 laser for dental alumina ceramic framework welding

O laser de CO_2 para a soldagem de infraestruturas cerâmicas de alumina

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ABSTRACT

Objective: Despite the increase of all-ceramic prosthesis in dental practice there is no evidence of the possibility of welding these structures if necessary. The objective of this study was to use CO_2 laser (λ = 10.6 μm) as a welding agent to fuse dental polycrystalline alumina ceramic. **Methods:** Ceramic blocks of pre-sintered alumina were sectioned into 20 bars (10.0 x 1.5 x 1.5 mm) and sintered to the final cross section dimension of 1.2 x 1.2 mm. The bars were adapted to an LHPG (Laser Heated Pedestal Growth) system device where the bars could be fixed in pairs and have their ends irradiated with CO_2 laser to fusion. The ring-shaped laser beam (300 μm thickness) was directed with the aid of mirrors to reach samples' ends. The laser was continuously applied (40 W nominal power, 5 seconds). After welding, the samples were analyzed in stereomicroscope and SEM. A diffraction analysis was carried out with one sample. **Results:** CO_2 laser was able to fuse the ceramic bars, but some of them showed some shape distortion in the fusion zone. The aspect of the fused alumina differed in color and translucency from the original sintered material. SEM evidenced the presence of porosity and voids in the center of the fusion zone. X-ray diffraction pointed to a reduction in crystallite size by two to four times in the welded region of samples. **Conclusions:** This study points to CO_2 laser as a possible welding agent to polycrystalline alumina dental ceramic. Porosity observed in the molten zone gives cause for concern regarding weld resistance.

KEYWORDS

Dental materials; Dental ceramic; Ceramic processing; Laser.

RESUMO

Objetivo: Apesar do aumento no número de próteses totalmente cerâmicas na prática clínica, não há evidência da possibilidade de se soldar essas estruturas se necessário. Este estudo testou o laser de CO_2 (λ=10.6 μm) como um agente de solda para estruturas cerâmicas de alumina policristalina. **Métodos:** Blocos cerâmicos de alumina pré-sinterizada foram seccionados na forma de barras (10,0 x 1,5 x 1,5 mm) e sinterizados na dimensão final de 1,2 x 1,2 mm. As barras foram adaptadas a um sistema de crescimento de fibras cerâmicas (LHPG – Laser Heated Pedestal Growth) onde as barras foram fixadas em pares e tiveram suas extremidades irradiadas com laser de CO_2 até a sua fusão. O feixe de laser foi direcionado com a ajuda de espelhos para atingir as extremidades das barras. O laser foi aplicado de forma contínua (40 W de potência nominal, 5 segundos). Depois da solda, os espécimes foram analisados em estereomicroscopia e MEV. Teste de difração foi conduzido com um espécime. **Resutados:** O laser de CO_2 foi capaz de fundir as barras cerâmicas, mas algumas delas mostraram uma distorção da forma na zona de fusão. O aspecto da alumina soldada diferiu em cor e translucidez do material original. O MEV evidenciou a presença de porosidade no centro da zona de fusão. A difração por raio-x apontou para uma redução no tamanho dos cristalitos de duas a quatro vezes na região da solda. **Conclusões:** Esse estudo mostrou ser possível usar o laser de CO_2 como um agente de solda para uma cerâmica policristalina de alumina. A porosidade observada na zona de fusão traz preocupação quanto à resistência da solda.

PALAVRAS-CHAVE

Materiais dentários; Cerâmica dentária; Processamento cerâmico; Laser.

INTRODUCTION

For many years, metallic alloys have been used in dental prosthesis framework manufacturing with good predictable results [1]. In addition to their mechanical strength, metallic structures present the possibility of being welded, if a misfit or failure occurs [2].

There are several welding processes for metallic framework in dentistry, with all types of welding presenting their own advantages and disadvantages [3]. Among these processes, laser is widely chosen for its advantages, such as its high penetration, lower piece distortion, and celerity [3,4]. Besides, due to its precision, laser allows welding in regions near resins and porcelains, and it also enables autogenous welding [5] (no filler metal addition). The process disadvantages include the residual stress that affects the final resistance of the welded structures and the presence of porosity in the joint area [3,5].

Recently, due to patients' aesthetic demands, metallic structures have been neglected, giving way to ceramic materials of more natural appearance. Dental ceramic materials have gone through deep modifications in their microstructure in the last decades. Mechanical properties of ceramic materials, specially have been improved and have allowed the introduction of ceramics as framework to extensive prosthesis [6,7]. The advent of polycrystalline ceramics was especially important in this context.

Alumina and zirconia polycrystalline ceramics are materials of higher fracture toughness when compared to porcelain or glass ceramics, and they may be used as fixed partial dentures (FPD) frameworks [8]. They usually present satisfactory marginal and internal fit [9,10,11,12]; however, to date, no previous studies regarding dental ceramic structure welding in cases of maladjustment or piece rupture have been identified in literature.

Ceramics usually present high melting points and need a high amount of energy input [13]. CO_2 laser and Nd:YAG lasers are well absorbed by ceramic structures and could be used in ceramic welding process with a high nominal power.

This preliminary study verified the hypothesis that CO_2 laser, under certain output and time parameters, can weld the sintered alumina used in dental prosthetic frameworks. The quality of the autogenous welding was determined by the microstructure observed in the fusion zone.

MATERIAL AND METHODS

Pre-sintered alumina blocks (AL-20, VITA Zahnfabrik, Bad Säckingen, Germany) were sectioned in bar-shaped samples of 10.0 mm length, with a 1.5mm cross-section. The bars were then sintered in a specific furnace (VITA ZYrcomat, VITA Zahnfabrik, Bad Säckingen, Germany) to their final length and cross-section, in dimensions of approximately 8.0 mm and 1.2 mm, respectively.

In pairs, the bars were adapted to a device used for ceramic fiber growth, in a process known as LHPG (Laser Heated Pedestal Growth). This LHPG system allows 2 bars to stay attached, one to a superior and the other to an inferior claw, with their ends in contact with each other. The claws are inside a chamber to avoid any risk to the operator. The LHPG apparatus was previously described in literature [14,15]. With the samples in close contact, a CO2 laser beam (λ=10.6 μm), with 40 W nominal power (Synrad Evolution 60-1, output power 125 W, Mukilteo, USA) was continuously applied for 5 seconds. The ring-shaped laser beam (300 μm thickness) was directed with the aid of mirrors to reach samples' ends. The ceramic heating resulted in a cylindrical fusion zone (1.0 mm radius, 1.0 mm height). (Figure 1).

Stereomicroscopy and SEM

The welded samples were analyzed by stereomicroscopy. Optical micrographs were obtained for qualitative analysis of the welding process using a stereomicroscope (Olympus SZ61) equipped with a CCD camera (Q-color 3, Olympus) with a 45x magnification ability. SEM images of up to 10^4 x magnification (Stereoscan 440, LEO) were obtained in order to evidence the micro structural aspect of the welding zones.

X-ray diffraction

The X-ray diffraction measurements were performed with a Bruker Discover D8 device equipped with a copper tube (λ=1.5418 Å), a Ni filter, and a Lynx-eye detector, operating at 40 kV and 30 mA, with 2θ from 10° to 140° with a 0.05° step and 10 s/step counting time. The samples (a reference ceramic and two samples welded areas) were measured with the small-slit-shaped X-ray beam in a way that the two different exposed areas were selected in both samples. The Scherrer equation [15] was used to calculate the crystallite size by fitting the experimental (104) and (110) diffraction peaks with Gaussian functions. The instrumental broadening was removed from the peaks full-width-half-maximum using a standard corundum reference sample.

RESULTS

The CO_2 laser in the studied parameters was able to weld the alumina bars and the LHPG device proved to be a useful tool throughout this preliminary study. During cooling, the shape of some samples' melting zones suffered some change, which resulted in misalignment of the welded bars.

Stereomicroscopy and SEM

Figure 2 shows the weld zone and its surrounding areas. It is possible to observe changes in ceramic translucency at the fusion zone (D) and a dark region at the weld interface (C).

SEM micrographs evidenced a substantial number of pores at the center of the fusion zone. A surface change at the fusion zone was observed at 10^4x magnification with the ceramic presenting a more vitreous aspect than in unaffected zone, as shown in figure 3.

X-ray diffraction

The diffraction test revealed a reduction in crystallite size by two to four times in the fusion zone when compared to the unaffected zone (figure 4). No new crystalline phase formation was observed. All peaks in the diffractograms corresponded to alumina (α-Al2O3).

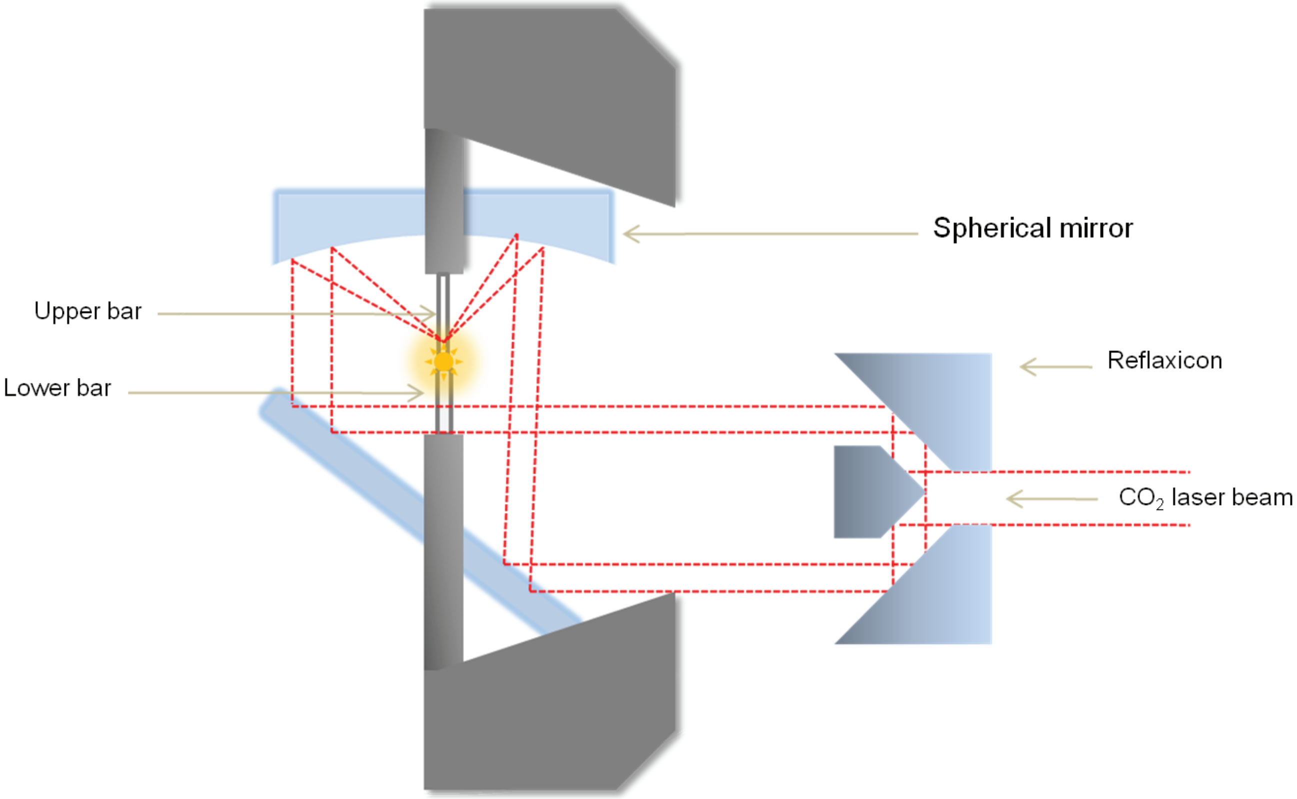

Figure 1 - Schematic representation of laser incidence inside the chamber where the ceramic bars were positioned.

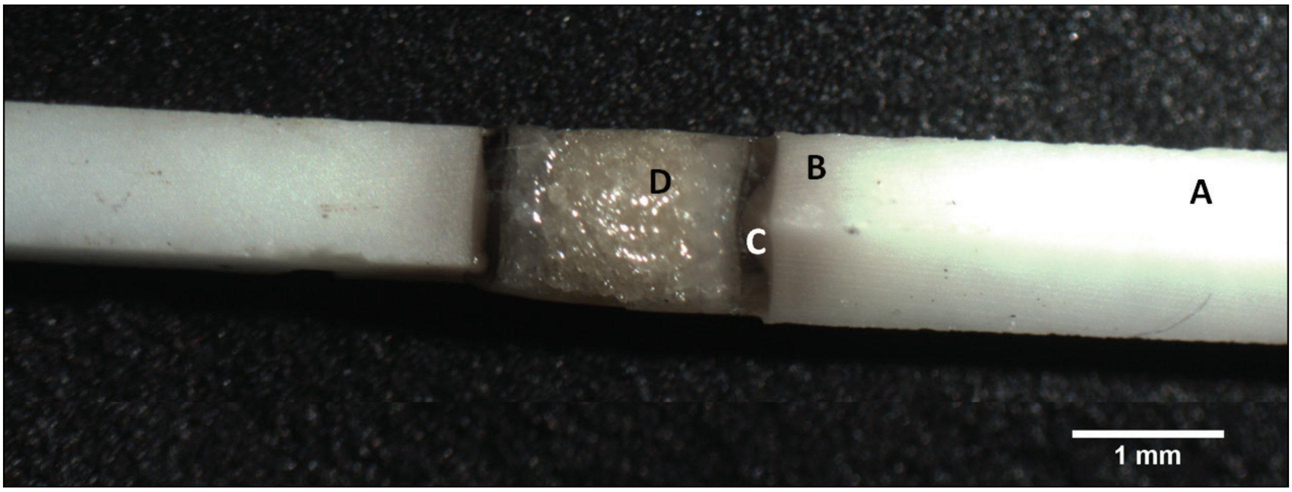

Figure 2 - Stereomicroscopy image (15x). A – Unaffected zone; B – Heat-affected zone; C – Weld interface; D – Fusion zone.

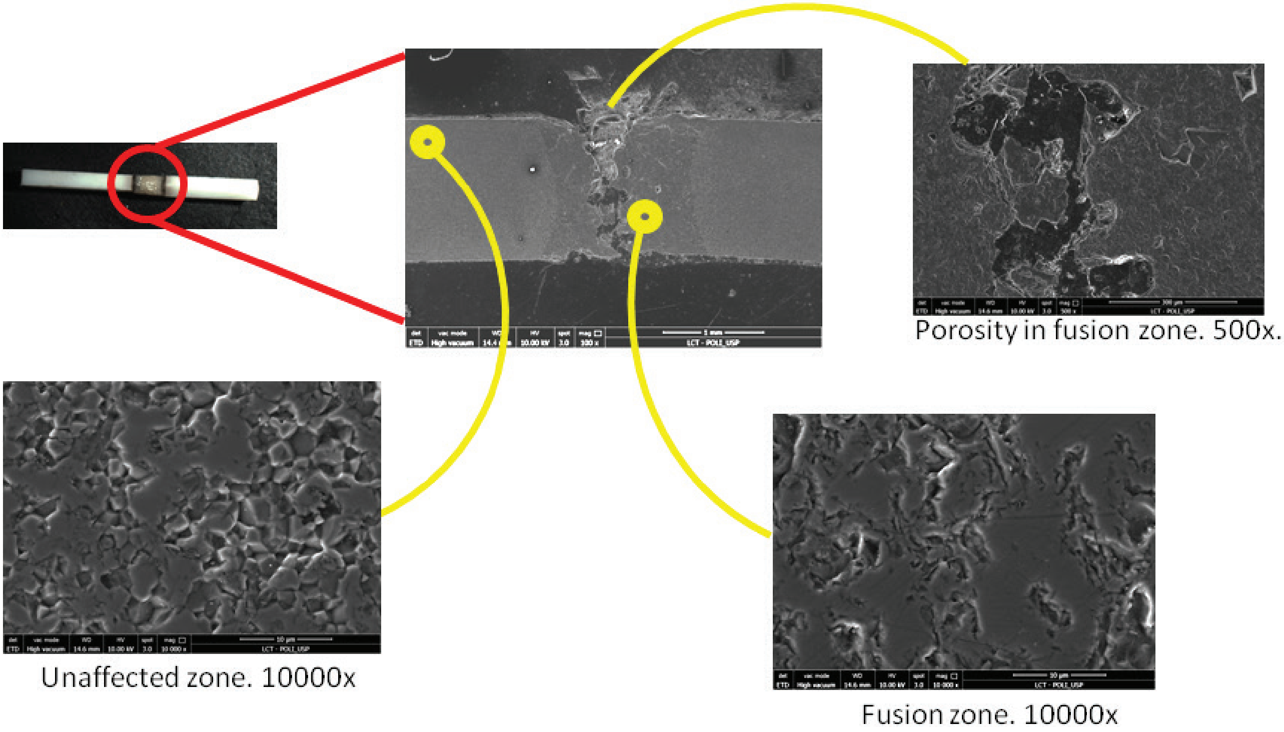

Figure 3 - Schematic representation of the various SEM micrographs from different bars' zones.

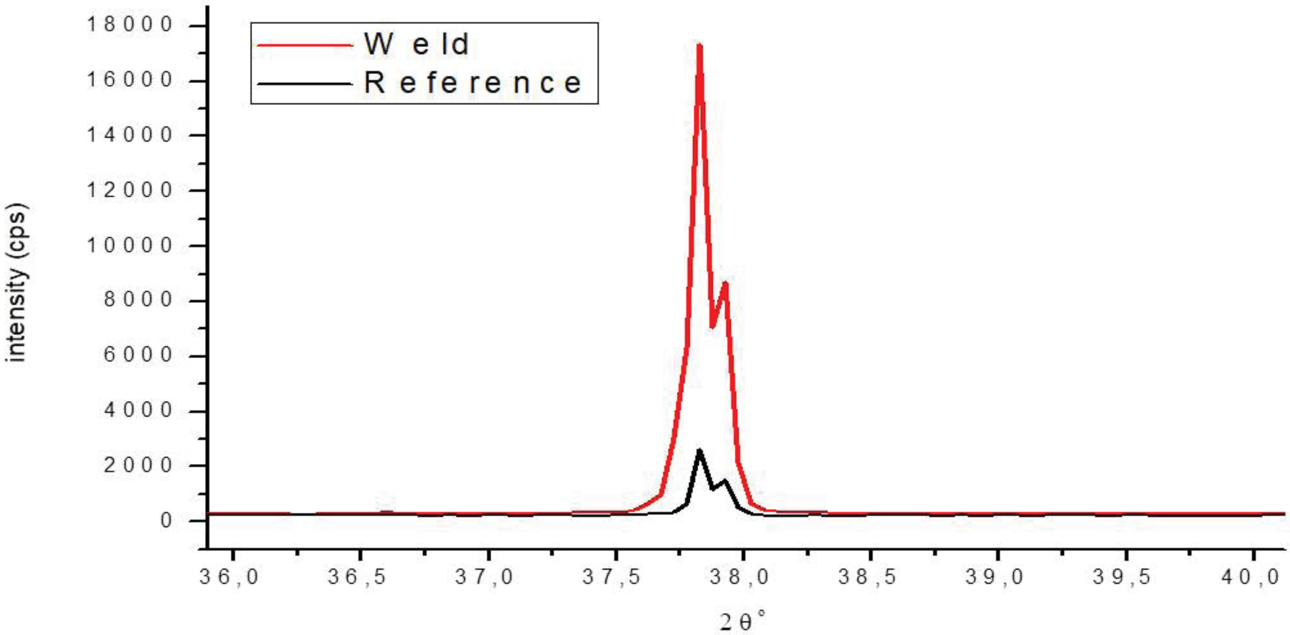

Figure 4 - Diffractogram showing the decrease in crystallite size at a specific measured peak.

DISCUSSION

This work tested the CO_2 laser as a heat source for the welding of an alumina ceramic usually applied to all-ceramic framework. To date, there are no scientific publications regarding this possibility in dentistry. Even if considering other areas of knowledge, studies related to ceramic welding testing are rare and quite experimental [17]. CO_2 laser was chosen for this study because is well absorbed by ceramics and presents a larger focusing diameter than Nd:YAG laser, which is also well absorbed by ceramics [13]. The hypothesis that CO_2 laser would be able to weld a ceramic alumina bar was accepted. However, bars distortion, color changes near the weld zone and porosity are some negative aspects of the proposed methodology and will be better analyzed below.

The incidence of all-ceramic fixed partial dentures (FPD) failures occurrence clinical conditions has already been presented in literature. A recent study [18] found an 8.8%-failure incidence of FPDs after 5 years of use. The 5-year framework fracture rate was 4.8%, being the second most common cause of failure. Full-arch all-ceramic frameworks have also been evaluated in a retrospective study [19]. The work evaluated the clinical performance of zirconia as a framework and observed a 17.6% framework fracture probability within a 5-year time frame. Therefore, the importance in developing a ceramics welding mechanism to be applied in the dental field becomes evident. The present study tested alumina polycrystalline ceramic, which is justified by the previous experience the authors have had working with this material in association with a CO_2 laser source, but with laser parameters setting adjustments. Hence, it is presumed that a similar welding process may be applied to zirconia bars.

The fact that polycrystal ceramics have been used in large scale in extensive prosthesis is noteworthy due to the recent significant improvement in their mechanical properties. The wider the frameworks are the harder is their passive settlement to the prepared teeth or to the implant abutment. In contrast, a non-passive settlement of the dental prosthesis may result in higher stresses transmitted to teeth or implant structure, or even produce a gap between the framework and the abutment, followed by bacterial biofilm formation. Therefore, when considering the traditional metallic frameworks, sectioning and welding frameworks were common procedures used to avoid such issues [20].

In this study, the LHPG device was used with two purposes: firstly, to align and hold the bars in position during the laser application and; secondly, to allow controlled and safe laser targeting for the operator. Although the device played its part in holding the bars in position, some fused samples showed some slight distortion after solidification, probably due to the thermal gradient between the fusion zone and the unaffected zone. This problem was exacerbated by the speed of the laser welding process, which resulted in fast cooling and may have generated thermal residual stress [21].

The laser used in the study should have the ability to induce the material temperature increase to its fusion, since it would simulate an autogenous weld without the addition of a filler. The possibility of merging or fusing dental ceramics with the aid of CO_2 laser has been previously demonstrated in literature [22,23].

Images from stereomicroscopy pointed to a microstructure change in the fusion zone, identified due to an alteration in its optical properties. A diffraction analysis confirmed that there was a reduction in crystallite size in the welding area, although no new crystalline phase was formed. The grain size reduction is justified by the rapid cooling of the melt zone with no time enough to allow crystal growth. In this case, a reduction in grain size resulted in an increase in material translucency, as reported in literature for other ceramic materials [24,25]. An important remark is that any color/optical change may be perceivable only in framework material. A previous study shows no translucency modification in veneer porcelain after CO_2 laser irradiance [26]. A study associating veneer porcelain to alumina framework should be considered.

A major concern was the great porosity found in the fusion zone, evidenced in the SEM micrographs. The pores were similar to macropores that result from some metal welding techniques and their presence may be explained by entrapped gas bubbles formed during the heating of the welded region [27]. The presence of small pores previously within the material could also contribute to the porosity by communicating to larger pores in fusion zone and growing throw gas diffusion [5]. However, the alumina blocks used in this study present low porosity after sintering [28].

The estimated temperature in the fusion zone was 2100 up to 2300 °C, above fusion temperature of alumina (2072 °C). The alumina fused and then crystallized in an extremely brief period of time (fast cooling rate) which would be a plausible reason for this entrapment of gases within the material.

Yamagashi et al. [29], 1993, emphasized that atmosphere parameter plays a key role in laser welding. Regarding the welding process of metallic structures, the shielding effect of some gases as argon is well known and used in dentistry to prevent oxidation and porosity in weld regions [30,31]. Nevertheless, the porosity observed and the mechanical properties on the joint region are extremely dependent on gas flow rate and the type of material to be weld. There are no evidences that the use of a shielding gas to a ceramic weld would result in any special benefit, but reducing hydrogen gas contamination would be interesting, since hydrogen is a common element that may remain entrapped in the material resulting in porosity after cooling [32].

Further studies should consider using a shielding gas or a controlled environment to avoid the possibility of the material contamination with moisture. New possibilities would also include the use of vacuum to test the reduction of pore formation. The material pre-heating would decrease the thermal gradient and crack formation. The lower cooling rate would probably reduce porosity formation by gas diffusivity through material and towards the surface.

CONCLUSIONS

Alumina autogenous welding with CO2 laser seems to be a viable process. Nevertheless, some improvements must be made in order to reduce the porosity formation in the fusion zone. Attention should also be given to optical changes in material.

COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of potential conflicts of interest

There are no potential conflicts of interest to declare. There was no financial support of any kind to this work.

Research involving Human Participants and/or Animals

This work did not involve human participants or animals.

Informed consent

This work did not involve human participants or animals.

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