Comparison between two techniques in laser welding of ceramics

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Comparison between two techniques in laser welding of ceramics

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Abstract. A pulsed YAG laser beam was used for joining SiO_2-Al_2O_3 ceramic tubes with 60 wt% alumina content. It was compared to another technique using halogen lamps to preheat the ceramic and a cw CO_2 laser to weld it, with respect to the processing parameters, the microstructure of the weld bead and the joint strength.

1 - Introduction

Many studies have been conducted on laser interactions with metals and semiconductors, but few have been done in the processing of ceramics with lasers.

The joining of ceramics to themselves may be important for making more complex structures, because the size or complexity of the structure render impractical or impossible a one-step processing.

One of the major problem in the fusion welding of ceramics is the control of cracking caused by thermal stresses. A previous solution has been to provide supplementary heating of a broader zone around the weld area with halogen lamps, so that no thermal stresses high enough to cause cracking are reached.

However, this heating device suffers mainly from two drawbacks : the space required and the incapacity of measuring any temperature with infrared pyrometer.

Another approach is to use the laser alone to preheat and weld so that processing conditions depend only on laser parameters (power, welding speed, position of the focal plane).

2 - Experimental procedure

The samples used are tubes (∅ 8/5 mm) of SiO_2-Al_2O_3 ceramics with 60 wt % Al_2O_3, and consist of mullite crystal and high silica glass matrix.

First of all, the object of trial was to preheat ceramics by using a 300 pw class YAG laser which allows an optical fiber beam transmission, and then to carry out butt-weld joints with the CO_2 laser (which has been used in previous tests with halogen lamps).

In fact, it has been noticed that the YAG laser can afford preheating and welding without using CO_2 laser, by making power density ramps.

3 - Welding experiment and discussion

The effects of the laser beam parameters (pulse frequency, position of the focal plane, welding speed) on the penetration depth and bead shape have been studied. In order to obtain a penetration depth of 100 %, without cracking, processing conditions are as follows (fig 1) :
Focal length : 100 mm
Welding speed : 30 cm/min
During welding : ∅ of beam : 0.5 mm
Power density : 1000 kW/cm^2 / Pm = 200 W

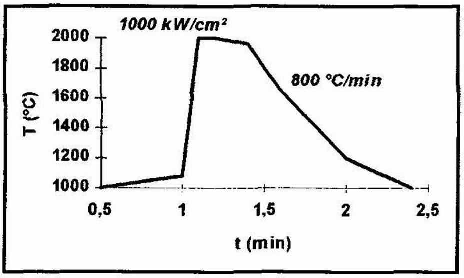


fig 1 : Thermal cycle (YAG laser)

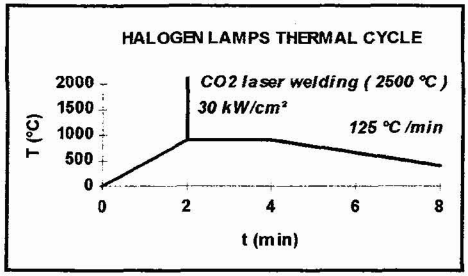


fig 2 : Thermal cycle (CO_2 laser)

To compare with CO_2 laser welding and halogen lamps preheating, the temperature is plotted against the cycle time in fig 2 [1] :In that case, welding requires a lower-power density (30 kW/cm^2), which is accounted for by the high alumina absorptivity at 10.6 µm (almost 100%) [3]. The amount of YAG laser beam absorbed in the mullite, which has heterogeneities on a scale of one wavelength or more, can be explained by a modification of the optical appearance by light scattering at grain boundaries or inclusions [2]. Specimens containing 99.5 wt % Al_2O_3 cannot be welded by YAG laser.

3.1 - Microstructure of the weld bead :

Figure 3 shows typical cross-sections of the weld bead observed with an optical microscope. Since ceramic material is porous, porosities tend to be produced in the weld bead. The larger viscosity of SiO_2 due to a lower temperature near fusion boundary prevents the bubbles in the melt from going up to the surface [4]. During welding, there are currents in the weld melting bath due to the surface tension gradient [5]. These currents drag the porosities in direction of the melt interface.

(a)

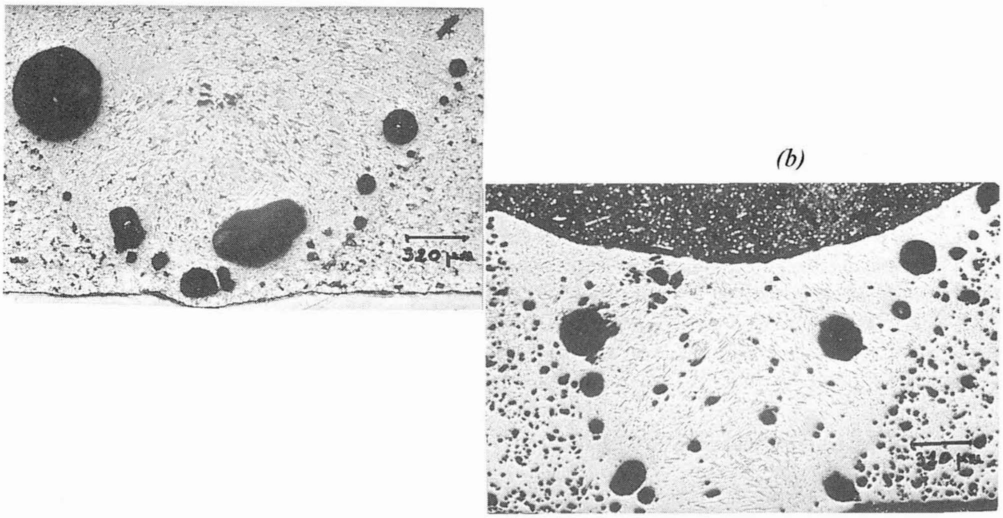
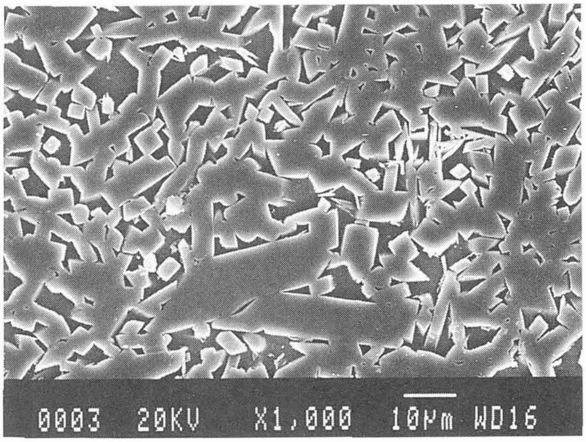


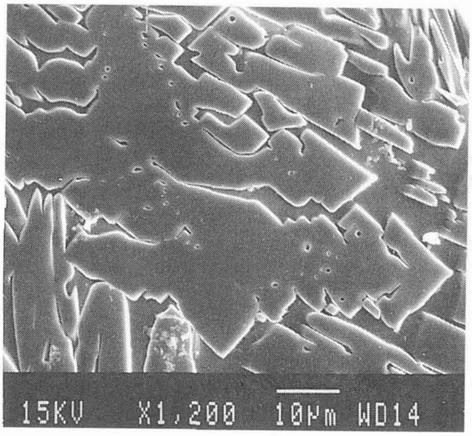
fig 3 : Cross-sections of weld bead with porosities at interface
(a) CO_2 laser - (b) YAG laser

Figure 4 shows SEM photographs of the microstructure of parent material (a), laser welding fusion zone with CO_2 (b), with YAG (c).The average size of mullite crystals has gone up from about 10 µm in the base material to 25 µm at the center of the bead (needle frame).

(a)



(b) *(c)*



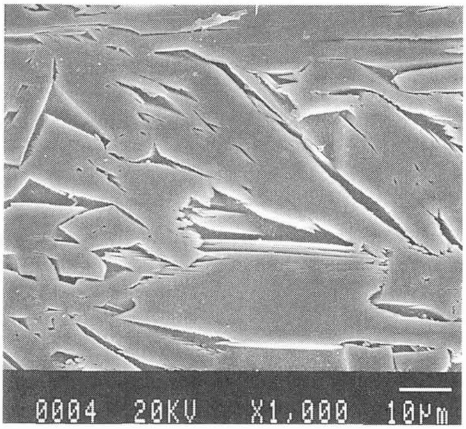


fig 4 : Microstructure of fusion zone, mullite needles in an amorphous silica glass

3.2. - Bending strength :

Strength of the weld joints was determined at room temperature in a 4-points bend test with a bend span of 35/10 mm. The bending strength of the base material was also measured and found equal to 128 $\pm$ 18 MPa.

Samples welded by YAG laser (fig 5.a) show an average bending strength a little lower then those welded by CO_2 laser (fig 5.b).

It was also found that, in this case, a largest number of samples fractured in the fusion zone.

Then, the average bending strength value of YAG laser welding ceramics can be accounted for by the presence of porosities in the weld bead.

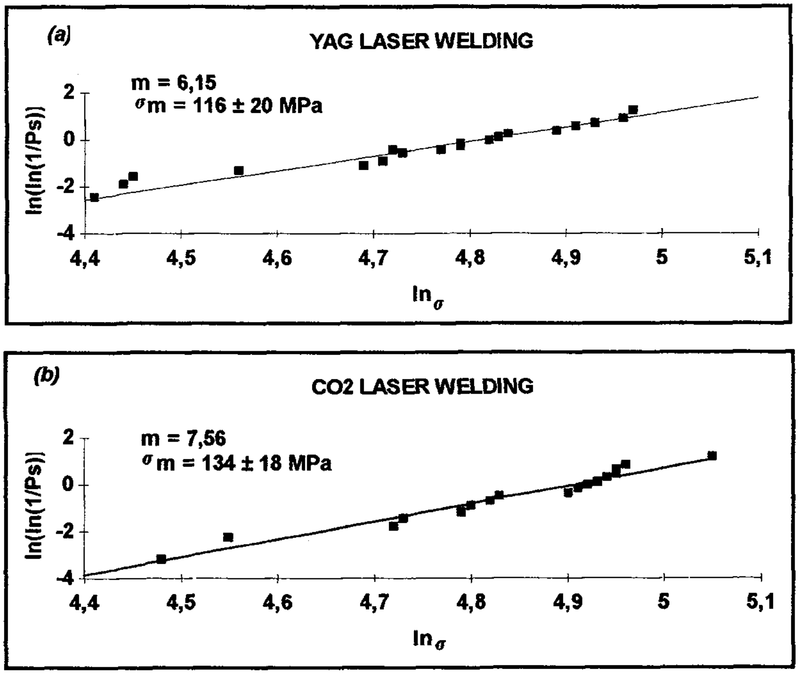


fig 5 : Weibull distribution plot of weld joints fracture strength data from tests done at room temperature
(a) YAG laser
(b) CO_2 laser

At last, hermeticity of the joints was confirmed for all specimens joined whether by YAG laser or CO_2 laser, by helium leak checking (10.10^{-9} atm.cm^3 / s).

4 - Conclusions

In this study, the process has been improved by using only the laser, and feasibility of such a process has been shown with a 300W pulsed class YAG. Since no significant difference in microstructure, vacuum-tight, penetration depth, and strength of the weld joint were seen between CO_2 laser and YAG laser welding, the last technique has made laser welding of ceramics more versatile for industrial applications.

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