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TITLE: PLASMA PHENOMENA DURING Nd-YAG LASER WELDING

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PLASMA PHENOMENA DURING Nd-YAG LASER WELDING

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INTRODUCTION

Laser welding is one of many processes used at the Los Alamos Scientific Laboratory (LASL) to fabricate prototype assemblies to be used for D.O.E. sponsored programs. The primary application of laser welding at LASL is for assembly of heat sensitive components and/or welding in gaseous environments at pressures significantly above atmospheric. Solid state, pulsed mode Nd-YAG systems are favored to obtain the maximum coupling efficiency with the wide range of metal alloys used. A characteristic of laser processing is the ability to deliver discrete, precisely defined quantities of energy to the work piece and to perform real time monitoring of the average power (watts) and the pulse characteristic (joules/sec) of the laser beam. It has been our experience, that when these operational parameters are controlled and the coupling action of the laser to the substrate in question is well characterized, then the process is sufficiently reliable to produce consistent, repeatable welding results. An exception to this observation is the welding of components in pressurized work chambers. Extremely erratic and unpredictable welding behavior has been experienced when the welding is performed at pressures above atmospheric.

An example of a high pressure welding application is the laser seal welding of inertial fusion (IF) experimental target assemblies. The laser is used to perform a seal weld at pressure and thus produce a gas-filled sealed IF target. This is an extremely sensitive welding procedure and we have encountered difficulties in obtaining consistent welding results, particularly as the gas pressure is increased above ~7 MPa. Investigation of this problem indicates that significant quantities of the laser energy can be absorbed by a plasma plume which is present during the time that the laser beam is interacting with the surface of the target material. [illegible] phenomena have been observed with CO_2 laser welding at atmospheric pressure and have been well documented in the literature (1,2). However, previous reports dealing with the Nd-YAG system indicate that absorption of laser energy in the plasma is of little importance since: a) transmission of the Nd-YAG beam is unaffected by the plume due to the shorter (1.06 μ versus 10.6 μ for CO_2) wavelength of the Nd-YAG, and b) the pulsed mode operation of the Nd-YAG prevents the plasma from reaching sufficient [illegible] to cause significant laser absorption. We could find no prior reference dealing with laser processing in high pressure environments. A series of tests was performed to attempt to gain a more comprehensive understanding of the problem.

EXPERIMENT DESCRIPTION

High speed photographic techniques were used to study the plasma formation under [illegible] conditions, [illegible] in flowing argon shield gas. The characteristics of the plasma [illegible] highlighted by [illegible] with a He-Ne laser which [illegible] placed behind the [illegible] directly [illegible] was run at [illegible] and [illegible] the characteristics of the [illegible] pulse length (1-7 ms), pulse shape, pulse repetition rate (10-200 pps), focus and average power (watts). A flat stainless steel substrate was used as the target material for most of these experiments. Figure 1 shows some selected frames representative of a 7-ms pulse. The plasma plume is fully developed almost instantaneously and the major portion of the laser pulse is, therefore, transmitted through the plume. Figure 2 shows the characteristics of the plume in more detail. An inner intense glow is surrounded by a less brilliant outer fringe which contains substantial quantities of particulate including solid pieces of weld spatter. The plume is extinguished between pulses and appears to conform exactly to the duration of the laser pulse. There was no single parameter that, by itself, had any significant effect on the characteristics of the plume formation. The intensity of the plasma appeared to increase with increased intensity of the laser energy delivered to the work surface.

A second series of experiments was performed using a transparent vacuum box to visually observe the effect of vacuum, argon, and helium gas environments. The laser was directed through a glass window and focused on a stainless steel plate. Figures 3, 4, and 5 show the variation in the visible plume at the various conditions. With a slight positive pressure in argon, the plasma is intense and localized above the target surface. The intensity is significantly less in the helium atmosphere, and in a vacuum of ~ 10 Torr there is very little plasma effect and the outline of the laser beam is defined, presumably due to the incandescent glow caused by interaction of the laser beam with vaporized metal. The weld penetrations obtained during these tests were also of interest, e.g., the welds in helium were three times as deep as those made in argon and the vacuum welds were twice again as penetrating as the helium welds. It should be noted that, in vacuum, the window inner surface is rapidly coated with vapor oxides which results in transmission problems. The final testing was an attempt to measure the effect of high pressure on weld penetration over the pressure range from atmosphere to 70 MPa. Figure 6 shows a schematic of the pressure vessel used for this study. A single pulse from the laser was directed through the sapphire window and focused at the target surface. A series of spot welds were made at varying pressures in hydrogen (deuterium) gas and the penetration measured as a function of gas pressure. Results are shown in Figure 7.

DISCUSSION

When the Nd-YAG laser is used in a welding mode, the interaction of the focused laser beam with the workpiece surface results in the initiation of a plasma plume. The appearance of the plasma corresponds precisely with the laser pulse width, irrespective of the pulse shape and/or frequency. The intensity of the plasma varies with the target material, the intensity of the laser radiation, and the type and pressure of the gas medium.

It is not within the scope of this paper to speculate on the [illegible] for initiation of the plasma. However, previous [illegible] relating to gas breakdown due to CO_2 laser [illegible] (1), [illegible] to account for this [illegible] the operating conditions of the Nd-YAG system.

The target of this investigation was the transmission of the laser [illegible] in the presence of a plasma. [illegible] penetration [illegible] to vary inversely with the intensity of the plasma [illegible] and the deepest penetration (maximum transmission) [illegible] obtained in vacuum.

The results obtained by [illegible] at very high pressure are [illegible] inconclusive [illegible] we would expect the [illegible] yield for [illegible] to decrease with increasing pressure, with an increase in plasma intensity and laser absorption. [illegible] lack of conclusive data relates to problems of conducting this type of experiment, and these experiments are being repeated to verify the data. There is, however, some degree of confidence in the general shape of the curve of Figure 7. A possible explanation for the shape of the curve is proposed as follows: at low pressure, transmission of the laser radiation is efficient with correspondingly good weld penetration; as the pressure and plasma intensity increase, the penetration decreases to a minimum value at which point heat transfer by radiation from the intense plasma becomes a factor in determining the depth of the melt zone. Radiation from the plasma is, therefore, a primary source of surface melting at the highest pressures examined in this investigation.

SUMMARY AND CONCLUSIONS

The plasma plume formed during welding with a pulsed Nd-YAG laser attenuates the laser radiation and directly affects weld penetration. The attenuation is proportional to the intensity of the plasma and, therefore, increases with increase in the gas pressure of the working environment. As the intensity of the plasma increases, heat radiation from the plasma becomes a significant factor contributing to the size of the melt zone.

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ACKNOWLEDGMENTS

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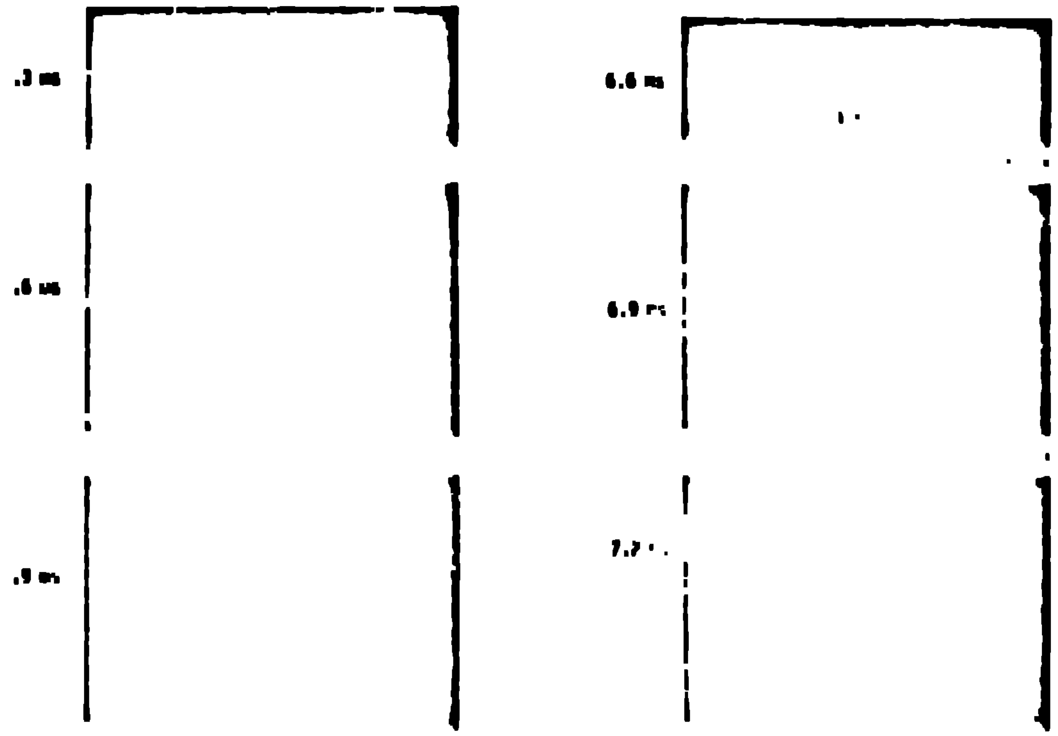
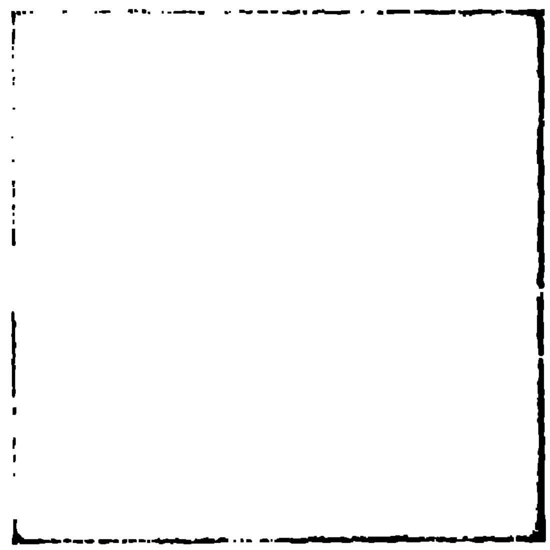


Figure [illegible] Selected fr[illegible]

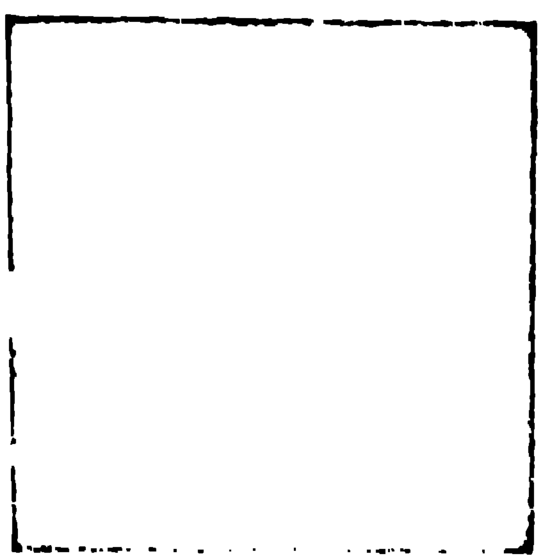
Single frame from [illegible] f.p.s. motion picture; laser power-350 watts, 7-ms pulse length, 30 pps, focused on stainless steel target material argon gas flow at atmosphere pressure.

Figure 2 Detail of fully developed plasma plume.



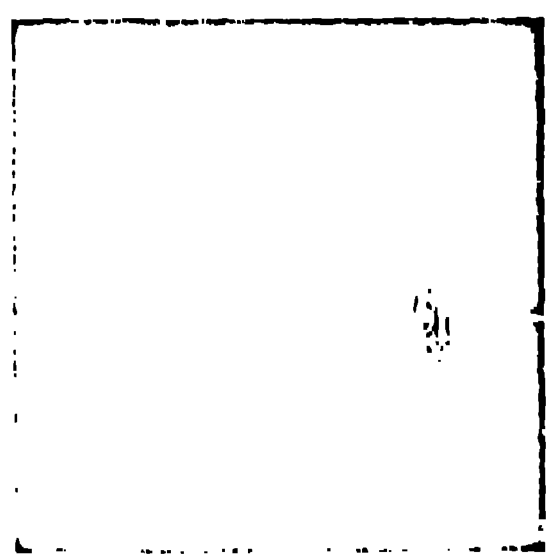
Chamber has slight positive pressure of argon 200 watts average power, 3.2-ms pulse length, 30 pps, focused on flat stainless steel plate.

Figure 3 Plasma appearance - welding in argon atmosphere.



As per Figure 3 but with [illegible]

Figure 4 Plasma appearance - welding [illegible] atmosphere.



[illegible]

Figure 5 Plasma appearance - welding in vacuum.

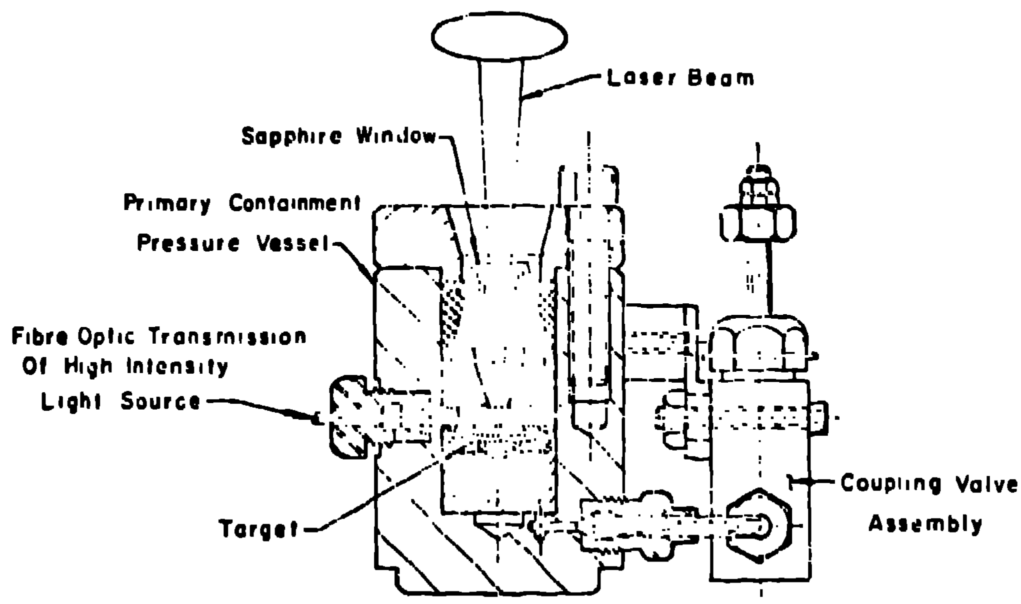


Figure 6 Schematic of pressure vessel used for testing at pressures ≤ 75 MPa.

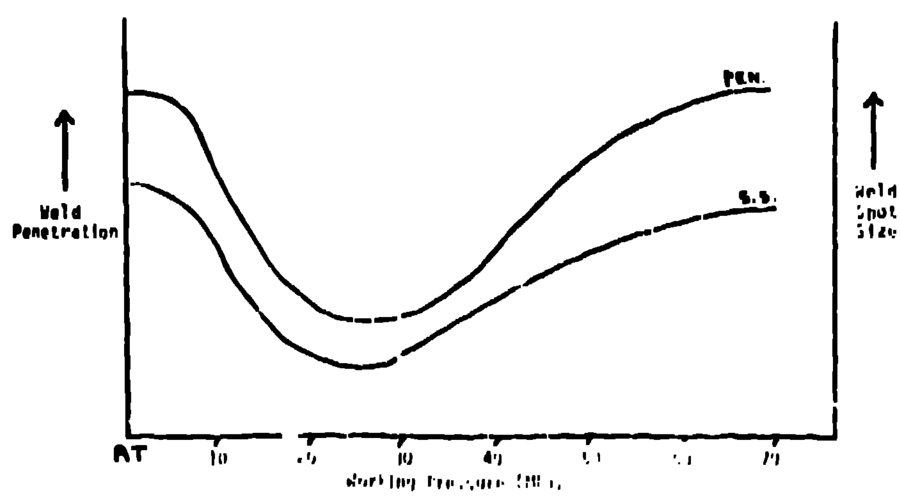


Figure 7 Graphic representation of effect of pressure on weld penetration and spot size.