# DEVELOPMENT OF COMBIND WELDING WITH AN ELECTRIC ARC AND LOW POWER CO LASER

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**ABSTRACT**

During the last two decades the laser beam has progressed from a sophisticated laboratory apparatus to an adaptable and viable industrial tool. Especially, in its welding mode, the laser offers high travel speed, low distortion, and narrow fusion and heat-affected zones (HAZ). The principal obstacle to selection of a laser processing method in production is its relatively high equipment cost and the natural unwillingness of production supervision to try something new until it is thoroughly proven. The major objective of this work is focused on the combined features of gas tungsten arc and a low-power cold laser beam. Although high-power laser beams have been combined with the plasma from a gas tungsten arc (GTA) torch for use in welding as early as 1980, recent work at the Ohio State University has employed a low power laser beam to initiate, direct, and concentrate a gas tungsten arcs.

In this work, the laser beam from a 7 watts carbon monoxide laser was combined with electrical discharges from a short-pulsed capacitive discharge GTA welding power supply. When the low power CO laser beam passes through a special composition shielding gas, the CO molecules in the gas absorbs the radiation, and ionizes through a process known as non-equilibrium, vibration-vibration pumping. The resulting laser-induced plasma (LIP) was positioned between various configurations of electrodes. The high-voltage impulse applied to the electrodes forced rapid electrical breakdown between the electrodes. Electrical discharges between tungsten electrodes and aluminum sheet specimens followed the ionized path provided by LIP. The result was well focused melted spots.

KEYWORDS
Gas tungsten arc (GTA), Combined welding, CO laser, low-power laser, Laser Induced Plasma(LIP)

## 1. Introduction

In recent years the laser-arc combined welding processes, so called "hybrid welding," is becoming popular industrial materials joining [1,2,3]. The laser offers reduction of welding distortion, high welding speed, and narrow fusion zones with good weld quality. Disadvantages include high initial capitol equipment cost, and the tight joint fit-up requirements of the process.

Investigations into arc augmented laser welding were conducted in the 1970s [4]. The physical characteristics and relative action for the laser beam and the electric arc were established on the basis of the experiments. Arc augmented high-power laser welding with the plasma from a gas tungsten arc torch was developed [5]. Increases in welding speed compare with the GTA were doubled, and improvements in penetration by as much as twenty percent were achieved over welding with the laser alone.

Similarly, developments of improved joint penetration and arc stability characteristics for aluminum alloys were investigated by combined use of high-power laser with GTA [6]. Nd:YAG and $CO_2$ laser beams combined with a plasma arc were applied for aluminum alloy 6061 and 6111 by using a coaxial end-effector which was designed to co-locate the arc torch nozzles the laser focused beam. Improved results of both absorption robustness and deep penetration for thin weld applications were observed.

When the beam from a sufficiently high-power laser is focused on the surface of a metal the arc plasma is guided to the location where the beam is melting and vaporizing the metal. However, the cost of a high-power laser makes this technique costly for industrial applications. This work describes efforts to develop a method using the beam from a low-wattage laser, such as CO laser, to produce the same improved arc stability and weld penetration results with a more economical arc systems.

In this work, the laser beam from a 7 watts carbon monoxide laser was combined with electrical discharges from a short-pulsed capacitive discharge GTA welding power supply. When the low power carbon monoxide (CO) laser passes through a special composition shielding gas, CO molecules in the gas absorbs the radiation, and ionizes through a process known as non-equilibrium, vibration-vibration pumping [8,9,10]. The resulting laser-induced plasma (LIP) was positioned between tungsten electrodes. A high-voltage impulse applied to the electrodes forced rapid electrical breakdown between the electrodes.

It has been verified that under certain conditions the electrical discharge between the electrode and aluminum and steel specimens followed the ionized path provided by the LIP. In the case of Aluminum specimen, a well-focused melted region has been achieved. In order to verifying the stability of a combined beam of laser and arc, the specimen was further bent to a deep groove configuration, and the melt spot was projected to the root of the deep groove.

**2. Experiment**

The combined welding of laser – GTA was performed using a self-developed carbon monoxide laser with a 7 watts continuous wave power. A capacitive discharge unit was used as a GTAW power supply. The schematic diagram of the overall experimental setup including the lenses is represented in the Figure 1. The CO laser beam comes from the laser source and is delivered to the cell, producing the laser induced plasma (LIP) in the special composition shielding gas within the cell. Figure 2 shows detailed construction of a test cell.

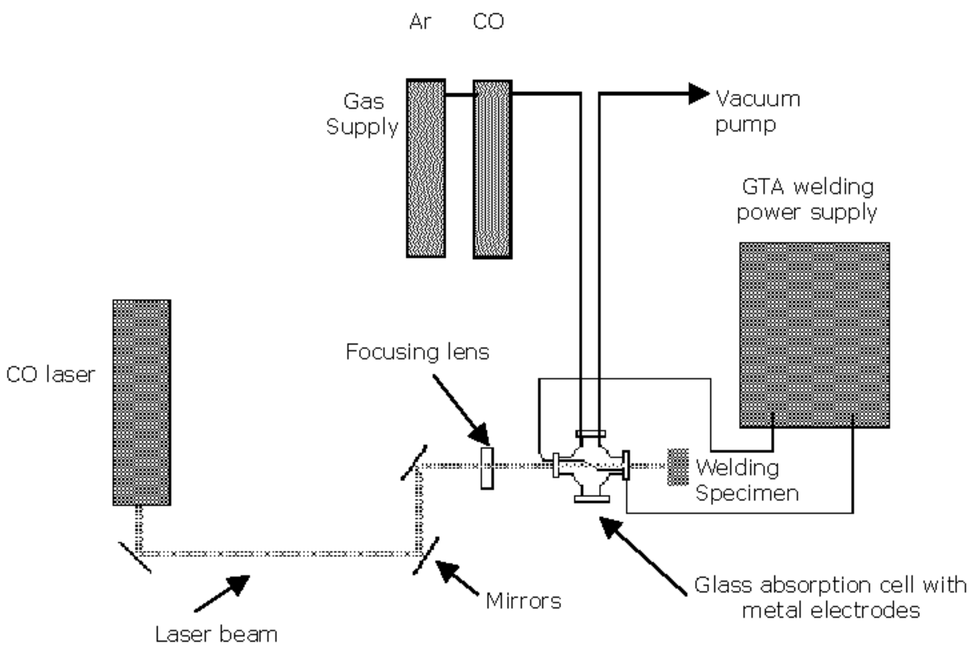



**Fig. 1** Schematic diagram of the overall experimental setup

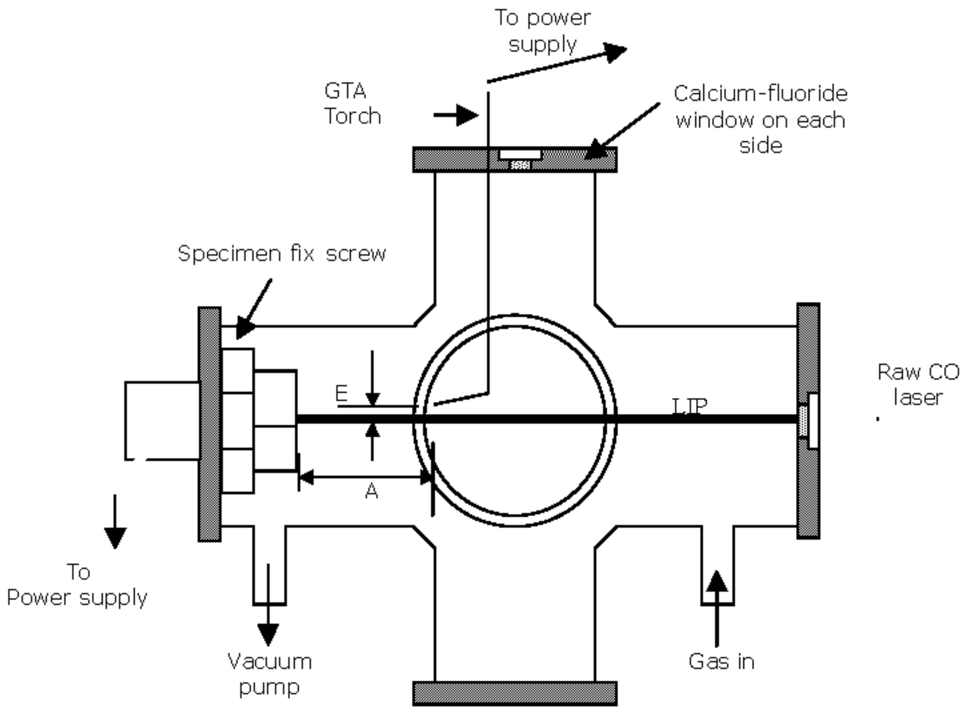


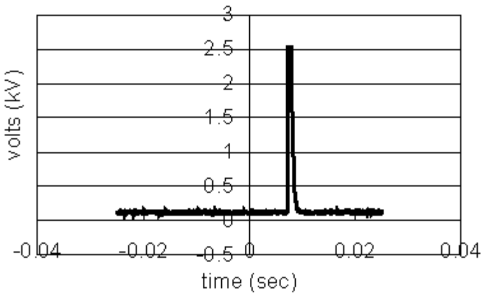

**Fig. 2** A detailed diagram of a optical absorption cell inside (side view)

The LIP sustained by a CO laser presents a rather unique environment, where strong vibrational nonequilibrium ionization can be established in a relatively cold gas. This cold ionization process is possible because selected molecules have a high absorption for a specific laser beam wavelength. A noneqilibrium state can occur in this environment by resonance absorption of the laser radiation into active atomic species, including CO or NO. Vibration-to-vibration up pumping also occurs, which results in strong overpopulation of the high vibrational levels of the molecules. Increased energy delivered to the upper most vibrational levels results in ionization.

As a result of the ionization of CO gas by the CO laser beam, a blue visible glow of the low-temperature LIP is observed. This LIP beam path has a relatively low electrical resistance. This visible path is electrically conductive and the electrical discharge favors this path.

Using mirrors and a 250 mm focal length lens for beam focusing before entering the optical cell, the focused beam is directed onto the sheet metal to be melted. The GTA welding power supply is connected to the tungsten electrode and electrical discharges pass between the electrode and the aluminum sheet. Argon gas is fed to the optical cell and is pumped from the cell to outside the room with a vacuum pump. The CO laser produces a continuous wave output with about 7 Watts of power as measured with a Convergent Energy power meter.

A capacitive discharge power supply was used in this experiment. The power supply has an intensity control that varies voltage from around 1 to 10 kV electrode. The polarity on the power supply was chosen electrode negative for this study. To determine the rate of discharge pulses, a PIN photodiode was used to view light from the electrical discharge front of the cell. The photodiode was connected to an oscilloscope and the time between discharges was measured. Fig.3 indicates pulse duration of about 2 ms for the arc at 3.7 kV across discharge capacitor. The proportional breakdown voltage is presented in Fig. 4, measured by a capacitive sensor at the same condition.



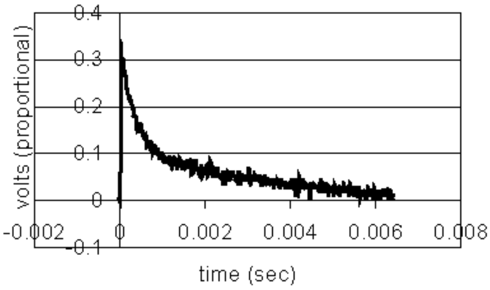
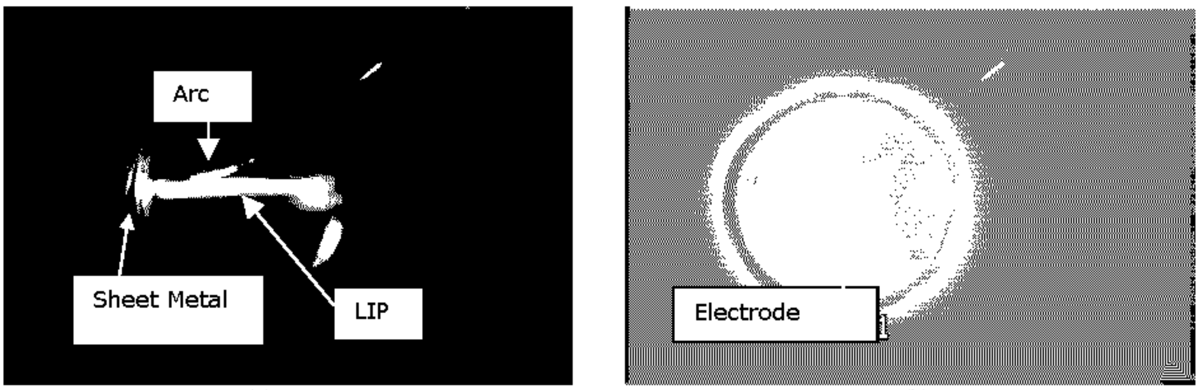




Fig. 3 Duration output of photodiode at 3.7 kV. Fig. 4 Breakdown voltage at 3.7 kV across discharge capacitor

The gas mixture contents were composed of 1% CO balance Ar at pressures of 100-700 torr. The CO in the mixture is prone to absorb laser light from a CO laser and ionize. The experiment was done inside a glass optical cell. Although CO gas at this concentration has virtually no toxicity, it was carefully contained to avoid setting off CO detectors in the laboratory required for safe CO laser operation. The length of the test cell is about 6 inch from the vacuum flange to flange. The diameter of the tungsten electrode is 2.5 mm and a focused spot of the laser-arc on the specimen is about 0.2 mm. The raw laser beam and LIP in cell could be moved by adjusting the mirrors and focused lens. The experiment was videotaped using a Sony Handycam, Digital 8 camera that records approximately 15 frames per second.

**2. Results and Discussion**

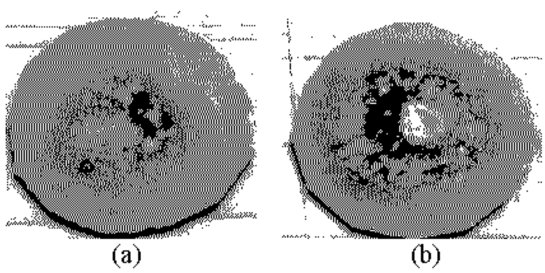
Fig. 5a is a photograph showing the LIP (horizontal blue beam) and the arc discharge (blue point raising from the central top of the LIP). Fig. 5b depicts the LIP after the arc discharge.




(a) (b)

Fig. 5 Electrical discharge between tungsten electrode and steel specimen: *(a) during the arc occur (b) after the arc occur.*

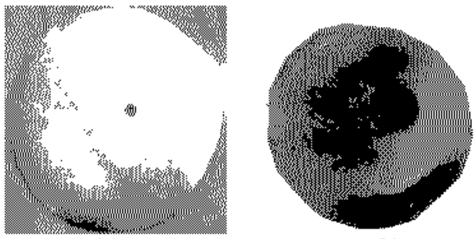
The results of the melted spot of 0.25 mm stainless steel specimens (diameter 15mm) at 14 kV and 9 kV and the pressure about 100 torr in the cell with 5 mm arc gap are shown in Fig. 6. As expected, the melted spot size and shape for a case of relatively high voltage were more stable compare with low voltage.



(a) (b)

Fig. 6 Results of melted spot of 0.25 mm stainless steel with P=100 torr, A=5 mm and E=1.5 mm for discharge voltage (a) 14 kV (b) 9 kV. The CO laser power is about 7 W.

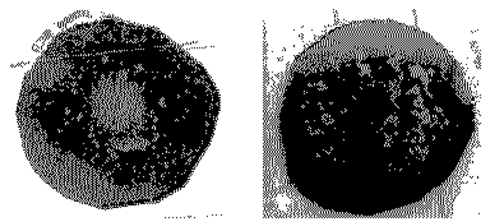
Fig. 7 shows the spots of 0.02 mm aluminum specimen with a pressure condition of about 600 torr using a focused beam (a) and unfocused beam (b). In order to get the focused beam a convex lens which has 200 mm focal length was used. The unfocused beam produced a spot diameter of about 1 mm without melting. The 0.2 mm focused beam diameter produced a very small spot (about 1 mm diameter) which melted completely through the aluminum.



(a) (b)

Fig. 7 Results of melted spot of 0.02 mm aluminum specimen with P=600 torr, A=8 mm and E=1.0 mm for a discharge voltage 3.5 kV and focused spot size (a) 0.2 mm (b) 1 mm. The CO laser power is about 7 W.

The results of effect on pressure difference in the cell are shown in Fig. 8. Typically, the pressure in the cell was a significant effect in establishing a stable LIP. When a pressure in the cell is close to atmospheric pressure the LIP was somewhat unstable. Lower pressure tended to cause more arc wondering, as seen in Fig. 8.



(a) (b)

Fig. 8 Results of melted spot of 0.25 mm stainless steel specimen with A=8 mm and E=1.0 mm for a discharge voltage 9.0 kV and pressure in the cell (a) P=670 torr (b) P=500 torr. The CO laser power is about 7 W.

**3. Conclusions**

A low power (7 watt) CO laser beam and resulting laser induced plasma in CO doped Argon shielding gas was used as a guide for a capacitive discharge arc. The welding arc pulse followed the LIP path and resulted in a melted spot on sheet aluminum and stainless steel.

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