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Effects of Xenon Cover Gas in CO₂ Laser Welding

By T. L. Hendrix

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Topical Report

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EFFECTS OF XENON COVER GAS IN CO₂
LASER WELDING

By T. L. Hendrix

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Topical Report
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Prepared by T. L. Hendrix,

Weld spatter in CO₂ laser welding is detrimental to miniature components. The effects of using xenon gas as an inert laser welding atmosphere to reduce weld spatter are discussed. The laser plume characteristics, weld penetration, and weld spatter are evaluated.

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SUMMARY

Xenon gas used as an inert CO₂ laser welding atmosphere has been proposed as a method to reduce weld spatter at Bendix. Weld spatter is not only costly to remove, but it can have a detrimental effect on the performance of complex mechanisms.

Xenon gas was introduced, using a 375 watt laser, under the same conditions that were used with argon gas which is the current inert atmosphere. Gas flow rate was the only variable used in this series of experiments.

Weld spatter was reduced but several trade-offs were encountered. There was a major decrease in weld penetration. The penetration ranged from 0.068 to 0.317 mm (0.0027 to 0.0125 inches). The penetration expected when argon is used is approximately 0.76 mm (0.03 inches). Also, a sooty deposit covered the weld bead and weld area when xenon was used.

DISCUSSION

SCOPE AND PURPOSE

Initial experiments using xenon gas as an inert CO₂ laser welding atmosphere proved to have definite effects on beam characteristics. It was initially theorized that xenon gas, having a molecular weight and density of approximately three times that of argon, the current CO₂ laser welding atmosphere, would cause a blanket effect on the volatile action of the molten weld pool thereby decreasing weld spatter. A literature search was performed and no evidence of any experimentation in this area was found.

ACTIVITY

In this series of experiments, xenon gas was introduced to the beam under the same conditions that were used with argon. The variable in the experiments was the flow rate which ranged from 0.5 L/minute to 12 L/minute. The 12 L/minute was the maximum xenon flow readable on the rotameter used. Eight bead-on-plate passes were made using xenon gas on type 304L stainless steel plate. The welding parameters were chosen to reflect the most ideal conditions to create weld spatter. Three bead-on-plate passes were made also using argon gas at the standard flow rate of 12.3 L/minute so a comparison could be made with the xenon plates. A count of weld balls every 12.7 mm (0.5 inch) was made on all plates. A plate section showing weld penetration was made for each bead-on-plate pass made.

The apparatus used in this experiment is shown in the line sketch in Figure 1. A 100-liter cylinder of xenon gas, grade 3, was connected to a standard argon regulator. The rotameter was added for a more accurate reading and flow rate control of the xenon gas. The work material used in this experiment was type 304L stainless steel plate which was cleaned and deoxidized prior to welding.

A 375 watt laser was chosen for this experiment because of past and current weld spatter problems. The initial laser set-up created the worst known welding conditions. This was done by welding at full power using 350 watts, 14.5 kV, 295 mA, and a continuously rapid-pulsed beam with a time on of 0.002 s and a time off of 0.002 s. The travel speed of the 51 by 203 by 3.2 mm (2 by 8 by 0.125 inch) 304L stainless steel plate was chosen to be 1.2 m/minute (50 ipm). Control of the travel speed and direction was done using a numerical control system. The laser beam

Figure 1. Line Sketch of Experimental Apparatus

was focused at the surface of the plate in all cases. Before the initial xenon experimentation, two initial bead-on-plate passes were run using the standard argon inert atmosphere at the currently used flow rate of 12.3 L/minute. These can be seen in Figures 2 and 3. During the two initial runs, careful observation to note the weld spatter was taken (Figures 2 and 3). Then, the 100-liter xenon bottle was placed on a stainless steel cart immediately outside the work station to keep a minimal line distance from the bottle to the work station. All welding parameters from the previous argon passes were identical except for the addition of xenon gas as the inert welding atmosphere. The line was purged for approximately 30 s before the beam was initiated, in each case, to ensure a complete cover. Eight sample plates were run using xenon gas. The flow rates were the only variable introduced while using xenon. Figure 4 shows the physical appearance of the beam plume using xenon gas. It was approximately doubled in size when compared to the argon. Then, a final argon gas test was run to ensure machine consistency (Figure 5).

A histogram (Figure 6) showing the amount of weld balls for each 12.7 mm (0.5 inch) of weld was made to compare the argon spatter with that of the xenon. As can be seen, a definite reduction in

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 2. Initial Bead-on-Plate Pass Using Standard Argon Atmosphere (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 3. Second Bead-on-Plate Pass Using Standard Argon Atmosphere (1.4X)

100 PERCENT ARGON FLOW

100 PERCENT XENON FLOW

Figure 4. Plumes as Seen Using Argon
and Xenon Welding Atmospheres

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 5. Final Bead-on-Plate Pass Using Standard Argon Atmosphere. (1.4X)

weld spatter was produced with the xenon gas. The major problem encountered in this test series was a decrease in weld penetration. Figure 7 shows the amount of weld penetration versus flow rate of both xenon and argon gases. The minimum weld penetration was approximately 0.068 mm (0.0027 inches) and the maximum weld penetration was 0.317 mm (0.0125 inches). A slight increase in penetration was shown with an increase in flow rate. Figures 8 through 15 show a sooty deposit which covers the weld bead and the immediate area. Approximately half of the plate was cleaned with acetone before pictures of the welds were taken.

The fact that the welding plume was approximately double in size in combination with the decrease of weld penetration indicates the actual power of the beam impingement to the plate was absorbed by the xenon gas. Future experimentation with flow angle variation could have the effects of blowing out the increased welding plume and allowing a more direct beam impingement. Also, the combination of argon and/or helium with xenon to slightly reduce the amount of density and molecular weight may allow a more direct beam impingement.

Table 1 is a summary of the flow rate, weld penetration, and average weld balls for each 12.7 mm (0.5 inch) with the increased flow rates used in this experiment. The xenon flow rates in these experiments were predicted using the method described in Sandia Laboratories report SLA-73-1006, Gas Flow Modeling of Variable Area Flowmeters (Rotameters) by H. L. Webster. The calculations are shown in the Appendix and in Figure A-1 of this report.

ACCOMPLISHMENTS

As a result of the tests performed using xenon gas, the following conclusions were made.

- The high density and molecular weight of xenon gas do affect the CO₂ laser beam characteristics.
- Weld spatter was reduced.
- Weld penetration was significantly reduced but increased slightly with an increase in the flow rate of xenon.
- A sooty deposit covered the weld bead and immediate area.
- A high pitched humming sound was evident when the xenon was used.
- The welding plume was approximately doubled in size when the xenon was used.

Figure 7. Weld Penetration Versus Flow Rate for Both Xenon and Argon Atmospheres

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 8. Xenon Sample 1 Bead-on-Plate, Flow Rate 7.4 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 9. Xenon Sample 2 Bead-on-Plate, Flow Rate 11.9 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 10. Xenon Sample 3 Bead-on-Plate, Flow Rate 3.4 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 11. Xenon Sample 4 Bead-on-Plate, Flow Rate 1.6 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 12. Xenon Sample 5 Bead-on-Plate, Flow Rate 2.6 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 13. Xenon Sample 6 Bead-on-Plate, Flow Rate 5.3 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 14. Xenon Sample 7 Bead-on-Plate, Flow Rate 0.6 L/Minute (1.4X)

WELD BEAD (15X)

CROSS SECTION (35X)

Figure 15. Xenon Sample 8 Bead-on-Plate, Flow Rate 1.2 L/Minute (1.4X)

Table 1. Summary of Weld Conditions

Gas Type	Plate Number	Flow Rate (L/minute)	Weld Penetration (mm) (inches)	Weld Balls*
Argon	Sample 1	12.3	0.787 (0.031)	23
Argon	Sample 2	12.3	0.711 (0.028)	12.5
Argon	Last	12.3	0.764 (0.030)	25
Xenon	7	0.6	0.787 (0.031)	9
Xenon	8	1.2	0.076 (0.003)	0
Xenon	4	1.6	0.127 (0.005)	0.1
Xenon	5	2.6	0.076 (0.003)	0
Xenon	3	3.4	0.101 (0.004)	0
Xenon	6	5.3	0.127 (0.005)	0
Xenon	1	7.4	0.228 (0.009)	0.2
Xenon	2	11.9	0.305 (0.012)	5.8

*Average number of weld balls for each 12.7 mm (0.5 inch)

FUTURE WORK

Plans for future experimentation basically involve the variation in flow angle and the combination of xenon with argon or helium to determine whether the use of xenon to eliminate laser weld spatter is a viable technique for mechanism production welding.

Appendix

CALCULATIONS FOR GAS FLOW MODELING OF VARIABLE AREA FLOWMETERS

The density of air is 0.075 lb/ft³ (1.2 kg/m³).

The viscosity of air is 184.67 micropoises (18.4 Pa·s).

The density of xenon is 0.3416 lb/ft³ (5.47 kg/m³).

The viscosity of xenon is 231.02 micropoises (23.102 Pa·s).

μ_1' = Viscosity of Gas 1 at reference conditions.

μ_2' = Viscosity of Gas 2 at same conditions.

p_1' = Density of Gas 1 at reference conditions.

p_2' = Density of Gas 2 at same conditions.

Q = Flow rate, volume per unit time.

$$\frac{\mu_1'}{\mu_2'} = \frac{p_2'}{p_1'}$$

$$\frac{\mu_1'}{\mu_2'} = \frac{184.67}{231.02} = 0.7993$$

$$\frac{p_2'}{p_1'} = \frac{0.3416}{0.075} = 4.555$$

$$\frac{p_1'}{p_2'} = \frac{\mu_1'}{\mu_2'}^2 \frac{p_2'}{p_1'} = (0.7993)^2 4.555$$

$$Q_2 = Q_1 \frac{\mu_1'}{\mu_2'} \frac{p_2'}{p_1'} = 2.9099$$

$$Q_2 = Q_1 \frac{0.7993}{2.9099} = 0.2747Q_1$$

Figure A-1. Scale Reading Versus Flow Rate for Flowmeter Calibration

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SPECIAL PROJECTS: Laser Welding

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