Laser welding under vacuum and varying atmospheric pressures

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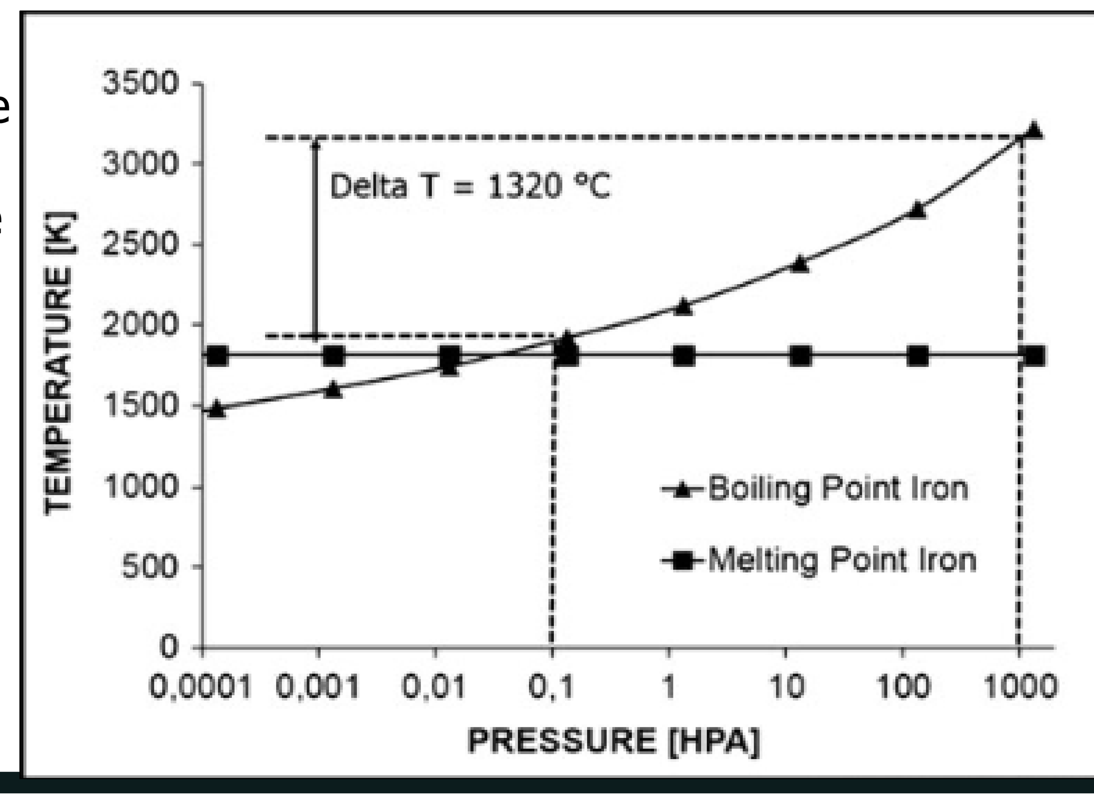
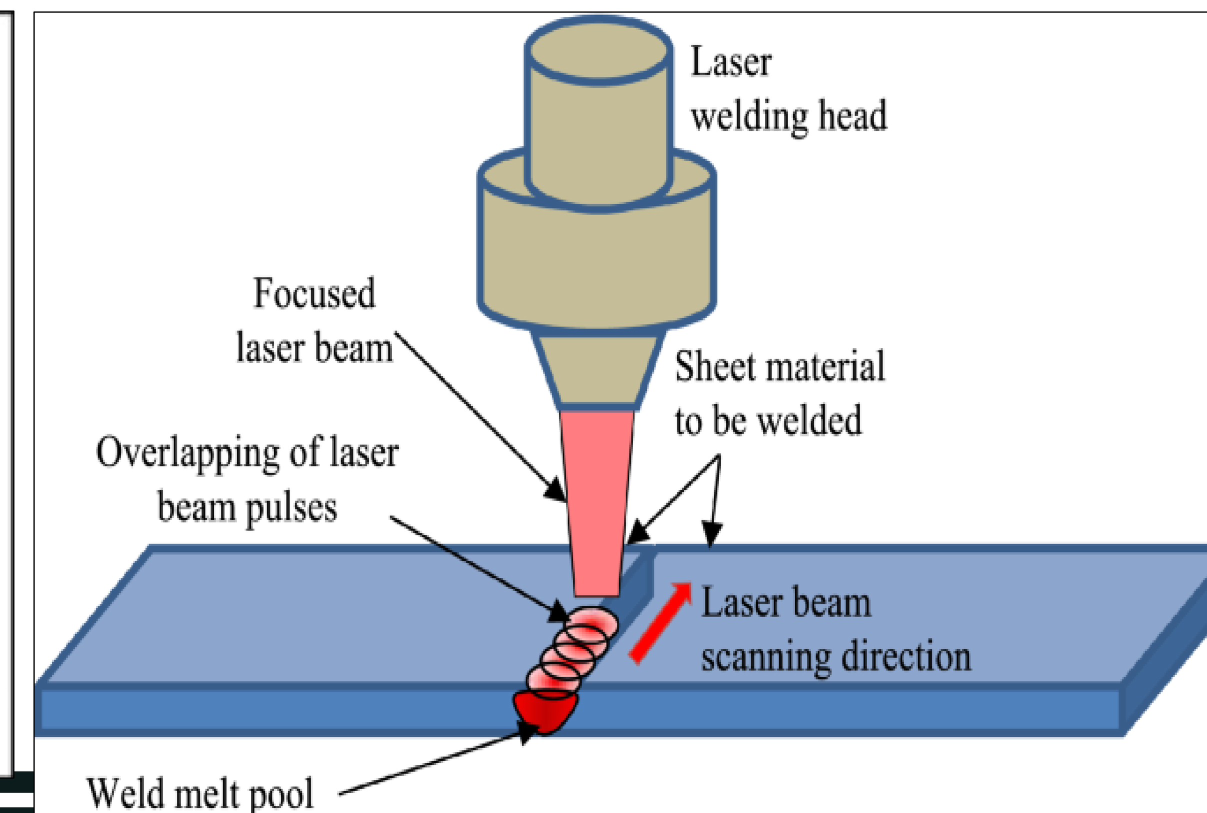
Background

Laser Beam Welding (LBW) is a process that uses high intensity light to join materials. This is possible due to the laser emitting a high amount of energy into a small area allowing for very low heat input, precise welds. There are many types of LBW such as continuous and pulse welding. Pulse welding releases energy in bursts instead of a continuous beam and allows for better heat control and reduces risk of damaging material. Welding under varying atmospheric pressures bring varying effects during welding such as increases in penetration or increased elemental vaporization. Studying these effects can allow for a greater understanding of LBW.





Motivation

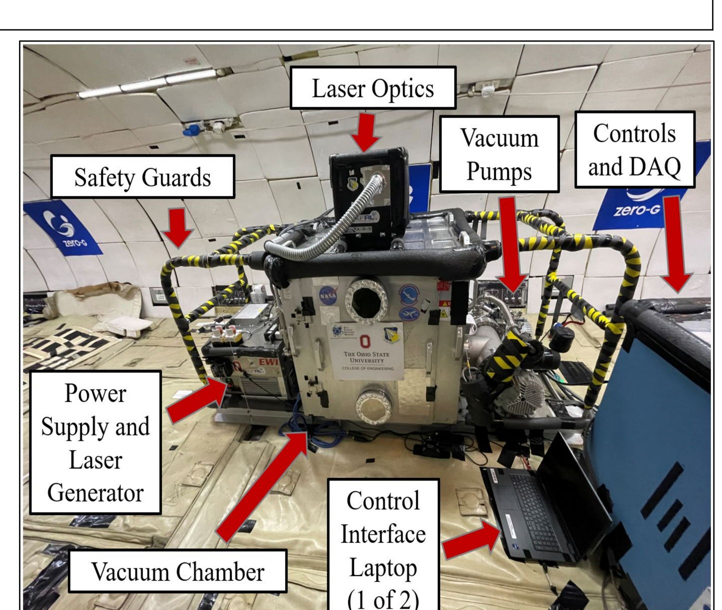
There is a critical need for comprehension of how chamber pressure influences the quality of welds in stainless steel. This knowledge can reduce costs in manufacturing and improve weld performance in many fields such as medical and aerospace. Welding under vacuum might be done to have more penetration into the weld for the same energy input or even by necessity from welding in space.

Objectives & Approach

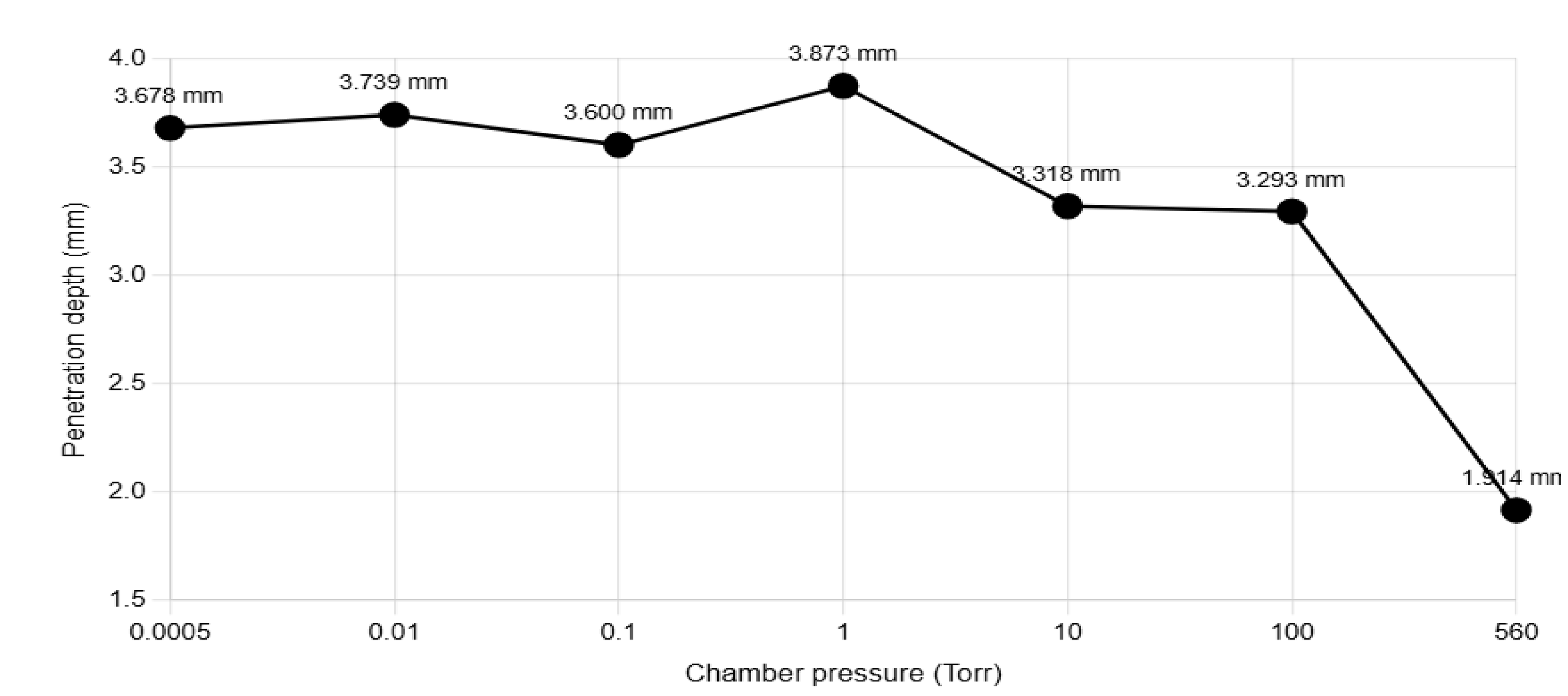
Characterize how variable atmospheric pressures affect LBW geometry, penetration depth in controlled, repeatable conditions. Welds were performed using a laser attached to a high vacuum chamber with backfill capability, enabling precise control of intermediate pressures between atmospheric and high vacuum conditions.

Power	Frequency	Pulse Length	Weld Length	Speed
900 W	40 Hz	4 ms	15 mm	4 mm/s

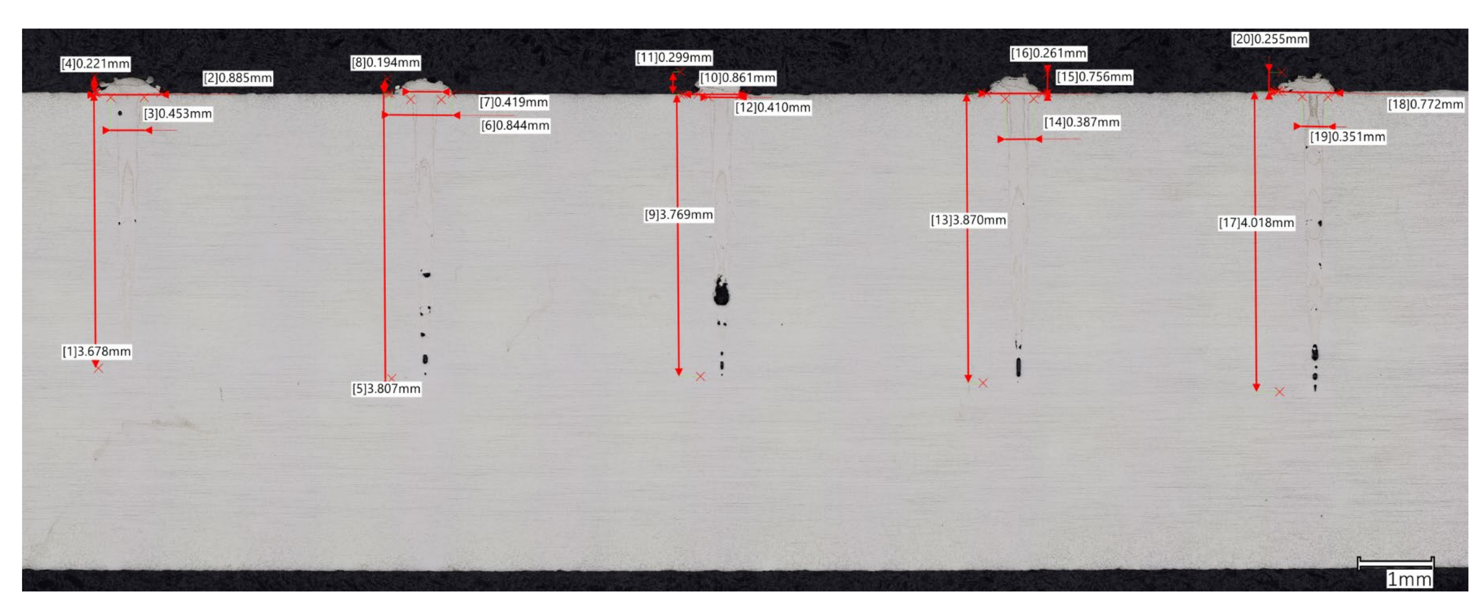
- Performed Pulse LBW on stainless steel at 7 pressure levels:
  560, 100, 10, 1, .1, .01, and .0005 torr
- 5 repeated rests conducted at each pressure level for statistical analysis.
- Cross sections analyzed for penetration depth, and bead morphology.



Results & Discussion



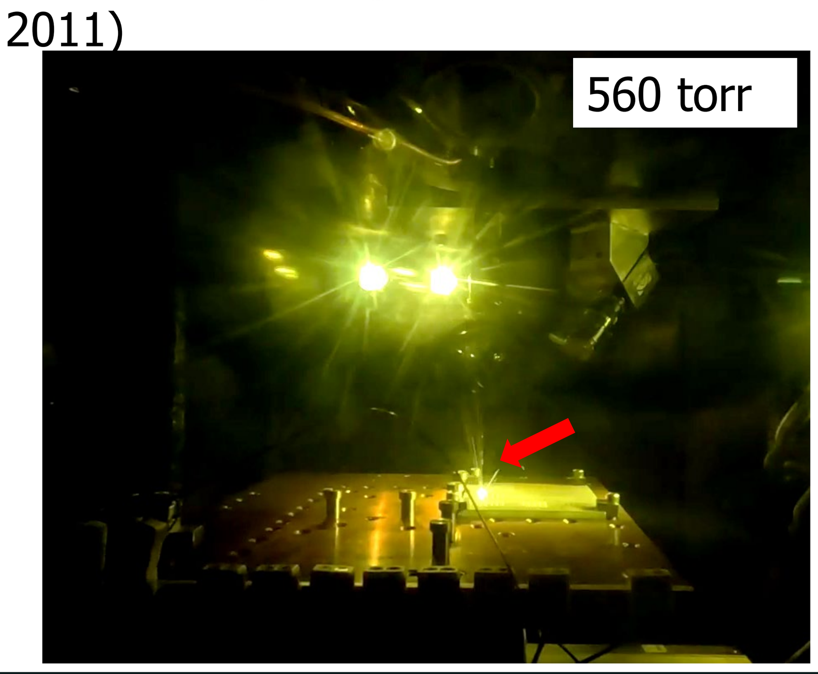
Penetration depth increases sharply from 560 to 100 Torr, then plateaus through high vacuum, consistent with plasma plume suppression and progressive lens coating reducing laser transmittance across successive welds.



.0050 Torr Sample

The important of this study comes from the fact that reducing atmospheric pressure increases weld penetration. Reducing atmospheric pressure increases penetration depth through two ways: first, the suppressed vapor plume absorbs less laser energy, allowing more of the beam to reach the keyhole; and second, and more importantly, the boiling point decreases with pressure which brings the metal closer to its melting point. Meaning metal vaporizes at lower temperatures, requiring less energy and making the keyhole process more efficient.

Results agree with literature — Katayama et al. (2011) found nearly double the penetration depth in 304 stainless steel when reducing pressure from atmospheric to ~10 kPa using a high-power disk laser. — (Katayama et al., *Physics Procedia*, 12, 2011)



Conclusions

Atmospheric pressure is a critical process variable in LBW — even small reductions from atmospheric pressure can improve weld quality in a meaningful manner. Penetration depth increased sharply between 560 and 100 Torr, confirming that plasma plume suppression is the main mechanism at moderate vacuum. High vacuum welds on stainless steel showed the greatest penetration depth. Lens coating across successive welds was identified as a source of variability that must be accounted for in future testing. These results support the development of a predictive model linking chamber pressure to weld output quality.

Future Work

Expand study to additional materials and alloys such as titanium and aluminum. Change laser parameters including power, frequency, and speed at each pressure to build a full process map. Investigate the use of a system for the internal lens to reduce transmittance loss across successive welds. Explore the precise transition pressure regime between 560 and 100 Torr in finer increments. Assess the industrial feasibility of partial-vacuum LBW as a cost-effective alternative to electron beam welding.

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