Laser Welding at Low Pressures

G. L. Goswami
Radiometallurgy Division, Bhabha Atomic Research Centre, Trombay, Bombay 400 085.

Introduction

Laser welding as an industrial joining process is perhaps no more than 20 years old, yet it has already developed to a stage where it provide direct competition to conventional welding processes and even to the electron beam welding (EBW) (1). The tremendous capabilities of the laser originate from its high energy density and fine focussibility obtained during the process of welding. Laser energy is absorbed by the surface of the weld joint and conducted away from the metal surface. The thermal processes taking place are markedly different as the energy density is varied starting from radial conduction to vaporization conduction to vapourisation loss to plasma formation over the sample. At relatively low energy density radial conduction mode is prevalent and is effective in thin welding. Vaporization conduction mode is operative in thick welding which is popularly referred as "Key-hole effect". In this process the rate of heating is very much higher than the rate of heat transfer by conduction mode and therefore, temperature at a local spot rises above the melting point resulting in vapour formation. These vapour are held in the liquid metal surrounded by the base metal forming a "Key-hole" and signifies the dynamic equilibrium of the heat and pressure conditions on moving object. During these operations in both thin and thick welding certain vapour are formed over the object which gets ionized by the incoming laser leading to its plasma formation. This laser induced plasma over the weld surface interferes with the incoming laser beam and lessens the effective intensity of beam thus limits the penetration especially at high power and low welding speed.

This problem can be overcome by welding at high speed necessitating the use of high power laser which is expensive. Alternatively pulsed output laser can be used where pulses are generated at a repetition rate more rapid than the thermal response time of the material, typically greater than 1KHz. The duration of each pulse is shorter than the time taken to generate the plasma thus enabling the beam to penetrate the material efficiently. Another alernate(2) is to disrupt the plasma by a high velocity jet of helium gas over the weld.

Laser welding at low pressure appears an interesting alternate as it limits the formation of plasma. Experiments have been conducted at different levels of low pressure (under vacuum) to study the gain in penetrations under both argon and helium gas at different value of laser pulse energies. In this paper results of laser welding at low pressures have been presented with stainless steel as the base material.

Experimental

A special evacuuable chamber was designed and attached to the laser welding system (Nd-YAG pulsed laser) as shown in fig.1. The pressure of the chamber was adjusted with the gas supply valve. Laser welding was performed on stainless steel 304 (thickness 3.1 mm) at different pressure (20 torr-760 torr) of both argon and helium gas at 8J and 13J laser pulse energy. All other parameters like welding speed (120 mm/min), pulse width (10ms) repetition rate (5Hz) were kept constant. Weld samples were later cut for metallographic examination and results are shown in fig.2 and fig.3. It is generally observed that laser plasma is perpendicular to the samples. In order to differentiate the effect of gas-plasma (argon and helium plasma) to metal-vapour plasma, experiments were conducted by inclining the sample to laser beam (as shown in fig. 1). Metal-vapour plasma is perpendicular to the sample while gas plasma is in direction of the laser beam. The results obtained in these experiments have been shown in fig.4.

Results and Discussion

Weld pool profiles of welds made under different conditions have been compared (figs. 2 & 3). Weld penetrations obtained under helium shielding are generally higher compared to argon shielding. Depth to width ratio of helium shielded weld is higher (fig. 5) than argon shielded weld. High penetration under helium gas is due to the better transmission (high work function) of laser though argon provides better shielding due to its high density. Similar observations have also been reported by Seaman(3). As expected the penetration with higher energy is higher than lower energy under identical conditions.

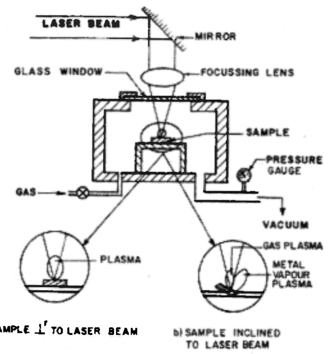

Fig. 1. *Experimental set-up*

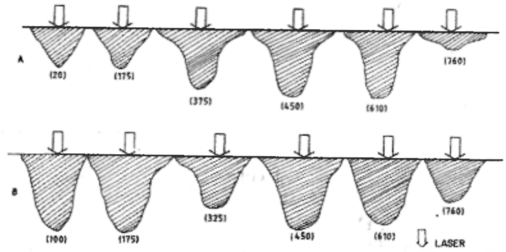

Fig. 2. *Depth of pentration at low pressure (A) In Argon (B) In Helium (Sample $\perp^r$ to the laser beam, E=13J, PW=10MS, RR=10Hz)*

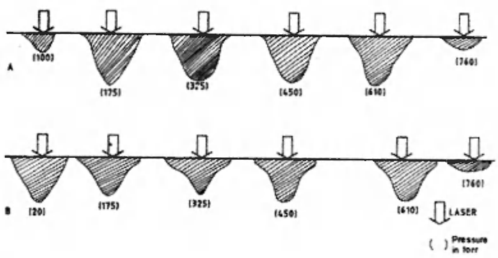

Fig. 3. *Depth of pentration at low pressure (A) In Argon (B) In Helium (Sample $\perp^r$ to the laser beam, E=8J, PW=10MS, RR=10Hz)*

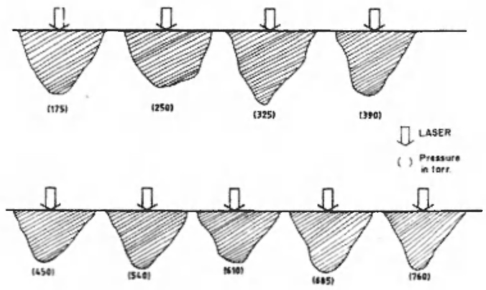

Fig. 4. *Depth of pentration at low pressure - Sample inclined to laser beam (E=13J, PW=10MS, RR=10Hz, In Helium)*

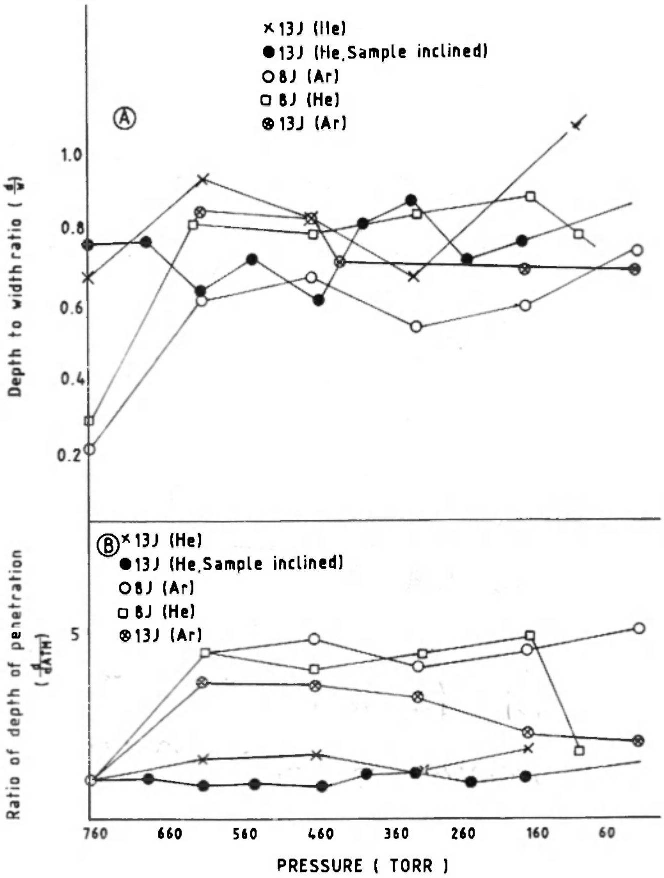

Fig. 5. *Effect of pressure Vs (A) Depth to width ratio [d/w] (B) Ratio of depth to the depth obtained at atmosphere [d/dATM]*

Most interesting results are high weld penetration at low pressure (fig.5) under both argon and helium gas. The highest penetration has been obtained in pressure range of 450-600 torr and penetration decreases at very low pressure (under high vacuum). As explained earlier, laser welding is a high energy density process which leads to surface metal evaporation resulting in plasma formation. This plasma shields the incoming laser and leads to reduction in penetration. At low pressure (450-600 torr) there is a reduction in the plasma formation (visually can be noticed during welding) over the samples and this results in increased penetration. The increase in penetration is about 3-5 times (fig.5) compared to the penetration obtained at atmospheric pressure. Under very low pressure (high vacuum) the vapourisation is higher resulting in high metal vapour plasma and this leads to reduction in penetration.

It is essential to find out whether this plasma contains both gas plasma (argon/helium) and metal-vapour plasma. Generally at such low value of laser energy the gas plasma is not expected and therefore, this increase in penetration is mainly due to the metal-vapour plasma. However separate experiment where sample was inclined to the laser beam has been conducted to differentiate these effects. This inclination tilts the metal-vapour plasma as metal vapour plasma is perpendicular to the sample while the gas plasma is in laser beam direction (fig.1). Thus the incoming laser avoids the metal vapour plasma but not the gas plasma (if formed). The results show that there is no change in penetration (fig.5) with the change in pressure (vacuum) as there is no shielding of laser beam by metal vapour plasma. This clearly demonstrate that metal-vapour plasma shields the incoming laser. Laser welding at low pressure (450-600 torr) increases the penetration 3 to 5 times the penetration obtained at atmosphere pressure. It may be mentioned that these pressure (450-600 torr) can easily be obtained by easy vacuum devices and evacuation line is also small. Productivity is, therefore, not affected when compared to electron beam welding where very low pressures (high vacuum) is needed for efficient welding.

Conclusion

It has been demonstrated that penetration in laser welding can be increased by a factor of 3-5 at low pressure. Maximum penetration is obtained in the pressure range of 450-600 torr. This order of vacuum can easily be obtained by simple vacuum system. The increase in penetration is mainly due to the limitation of metal vapour plasma at low pressure. This is a vary useful technological observation as it increases the capacity of the laser welding system.

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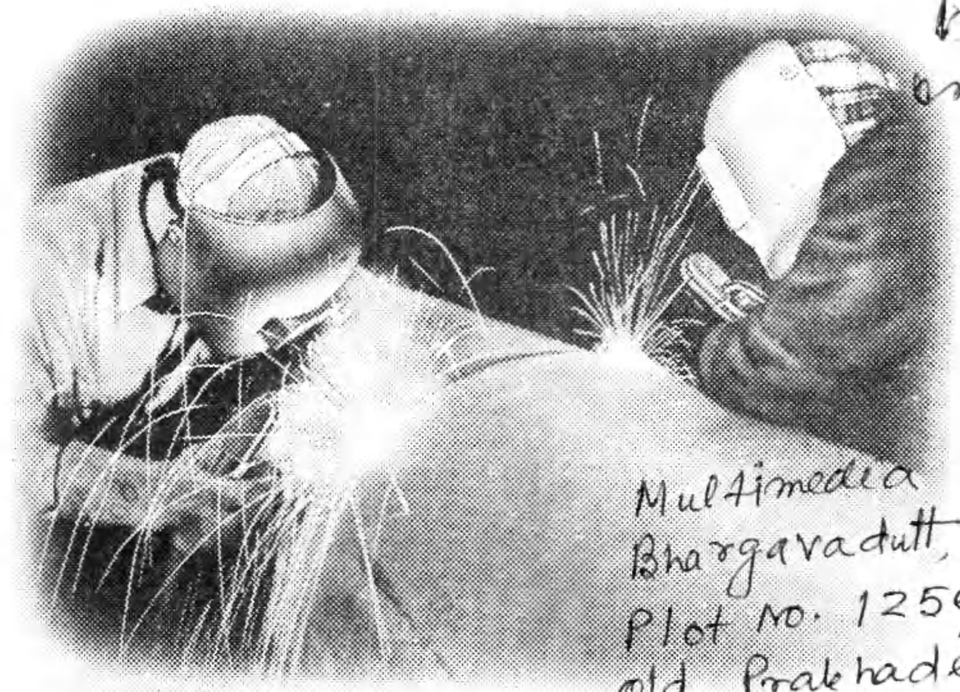

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