Plasma channel formation for triggering arc welding

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A method of starting arc welding using a plasma channel formed between electrodes in a tungsten inert gas arc welding system was demonstrated. The plasma channel was generated by gas breakdown in the laser beam path. In a previous study by the present authors, the arc welding could be started using a laser produced plume. Results in the present study indicated that the laser energy required to start the process using the plasma channel was lower than that using the plume. STWJ/382

Keywords: pulsed laser, plasma channel, plume, arc, arc discharge, arc welding, gas breakdown

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INTRODUCTION

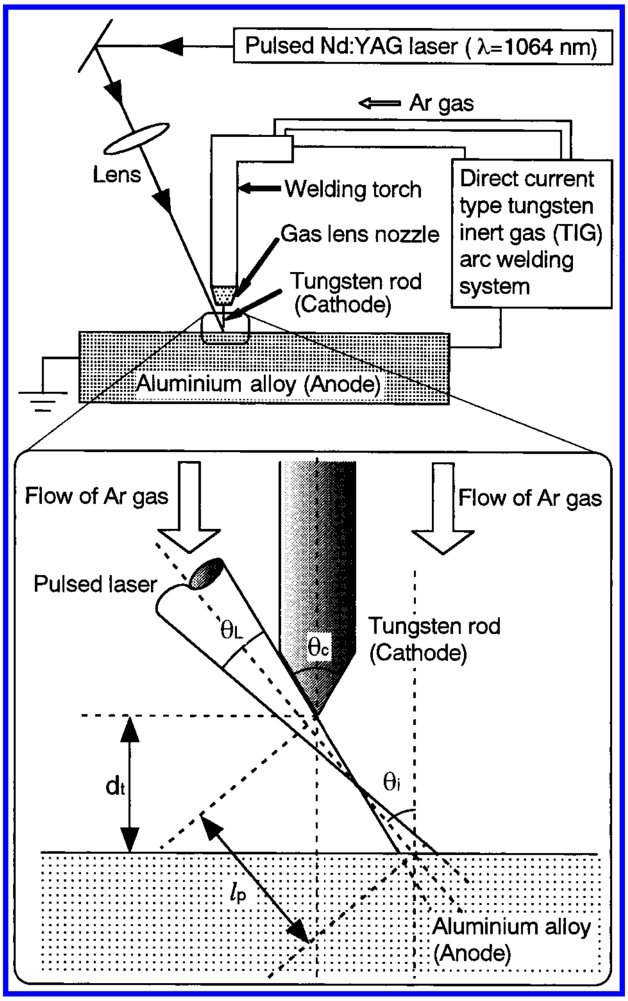
Tungsten inert gas (TIG) arc welding uses an arc produced between the cathode (tungsten rod) and anode (workpiece).[1] To start the process, a method for triggering the arc discharge between the electrodes is required. The touch, high frequency generation, or high voltage pulse starting methods are conventional techniques for triggering arc discharge.[2] In addition to a welding power source, high frequency generation and high voltage pulse starting methods require a high frequency and a high voltage generator, respectively, to produce ionised gas for the triggering process.[2,3] High frequency radiation may disturb radio, electronic, and computer equipment.[2] A high voltage generator may require an additional electric circuit to prevent accidents.[3] In the touch starting method, the rod is lowered to the workpiece until contact is made. To accomplish triggering, the rod is rapidly withdrawn a short distance. This method does not require any power generators except for the welding power source. This simplicity is the advantage of the touch starting method. However, the touch starting method also has the disadvantage that the rod tends to stick to the workpiece, causing electrode contamination and transfer of tungsten to the workpiece.[2]

A plasma channel can be used as an electric path, which consists of gas ionised by a pulsed laser at a laser intensity exceeding the gas breakdown threshold.[4,5] When the plasma channel is produced between the electrodes, the tungsten rod can be electrically connected with the workpiece. This laser triggering method can avoid the above mentioned disadvantage of the touch starting method. The technology utilising the gas breakdown induced by a pulsed laser has already been effectively applied to a laser triggered spark gap.[6] However, there have been no reports on the utilisation of this method for triggering arc discharge in the TIG arc welding system. The plasma channel must be produced in argon gas since argon gas is usually used to shield the rod and the molten metal of the workpiece. Formation of the plasma channel depends on the gas breakdown threshold in argon. If the workpiece has an oxide film on its surface, the triggering occasionally fails in the conventional methods owing to increased resistance on the workpiece surface. The oxide film is naturally formed on workpiece materials such as aluminium alloy in air. The laser triggering method can avoid this problem since the laser beam irradiates the surface of the workpiece and ablates the oxide film. The oxide film vaporised by the laser ablation is a part of the plasma channel and is utilised in the triggering process.

In the present work, it has been demonstrated that arc discharge triggering in the TIG arc welding system was achieved using the plasma channel produced by focusing a pulsed laser. The laser beam was focused into the argon gas between the electrodes. Since it was necessary for the plasma channel to have sufficient length to form an interconnection between the electrodes, its formation was observed before the triggering experiments were carried out. Minimal laser energies for triggering as a function of distance between the electrodes were measured. In a previous study by the present authors, a laser produced plume could start the arc welding when it was similarly used as an electric path between the electrodes.[7] The minimal laser energies required for triggering using the plasma channel were compared with those required using the plume.

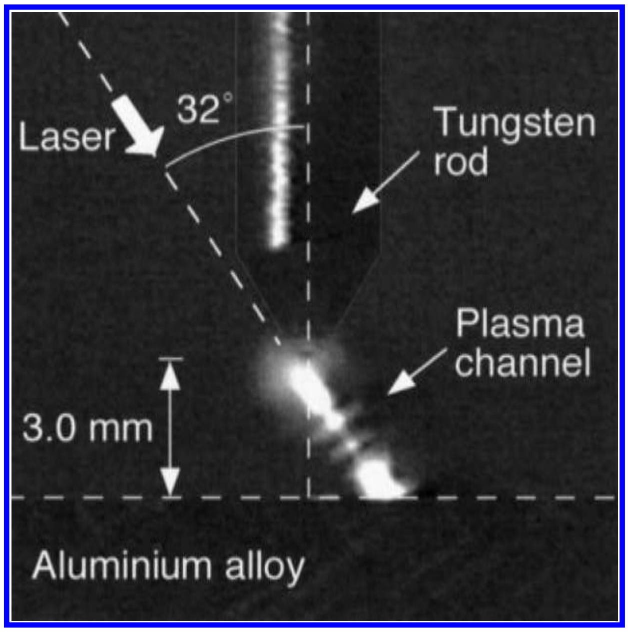
EXPERIMENTAL CONDITIONS

A schematic diagram of the experimental configuration is shown in Fig. 1. As shown in Fig. 1, a pulsed Nd:YAG laser was added to a direct current type TIG arc welding system with a maximum current of 300 A. The TIG arc welding system had a high frequency generation circuit for starting the arc. Since the high frequency generation starting method was not required in the method proposed in the present work, the circuit was deactivated before carrying out the experiments. The cathode consisted of a tungsten rod 3·2 mm in diameter, which had a conical tip. The solid angle θ_c of the conical tip was 60° in the present experiments. The rod was held by the welding torch along with the gas lens nozzle of 12·7 mm diameter. Argon gas was ejected using the nozzle at a gas flow rate of 10 L min^{-1}. An aluminium alloy (AA 5083) plate was installed as the anode under the rod. The distance d_t between the electrodes in TIG arc welding usually varies in the range 2–3 mm. Wavelength, pulse length, and beam



1 Schematic diagram of experimental configuration for triggering arc discharge, employing direct current type tungsten inert gas arc welding system and pulsed Nd : YAG laser: cathode and anode of system consisted of tungsten rod and aluminium alloy plate, respectively, and laser beam was focused into argon gas ejected from nozzle between electrodes by lens of 150 mm focal length at incident angle of 32°

diameter D of the laser were 1064 nm, 7 ns, and ~8 mm, respectively. The laser beam was focused into the argon gas ejected from the nozzle between the electrodes by a lens of focal length f=150 mm. The cone angle θ_L of the laser beam was 3·1°, given by $\theta_L=2\tan^{-1}(0.5D/f)$. The incident angle θ_i of the laser beam to the plate was given by $\theta_i>\theta_c/2+\theta_L/2$ to prevent the rod from being irradiated by the laser beam. Since θ_c and θ_L were 60° and 3·1°, respectively, the minimum value of θ_i was 31·5°. The laser beam was focused at θ_i=32° in the experiments. The length l_p of the plasma channel required for triggering was given by $l_p=d_t/\cos\theta_i$ as shown in Fig. 1. Therefore, the required l_p values were 3·6 mm for d_t=3·0 mm and 2·4 mm for d_t=2·0 mm, respectively. The length of the plasma channel was controlled by changing the focal position in addition to the laser energy. The plasma channel formation was observed using two charge coupled device cameras. The conical tip of the rod was placed at the edge of the plasma channel. After the placement of the conical tip, a bias of about 60 V was applied between the electrodes to trigger the arc using the plasma channel. In the experiments, d_t was varied from 1·5 to 3·5 mm. The minimum laser energy required to achieve triggering was measured for d_t values between 1·5 and 3·5 mm varying in 0·5 mm steps. In the

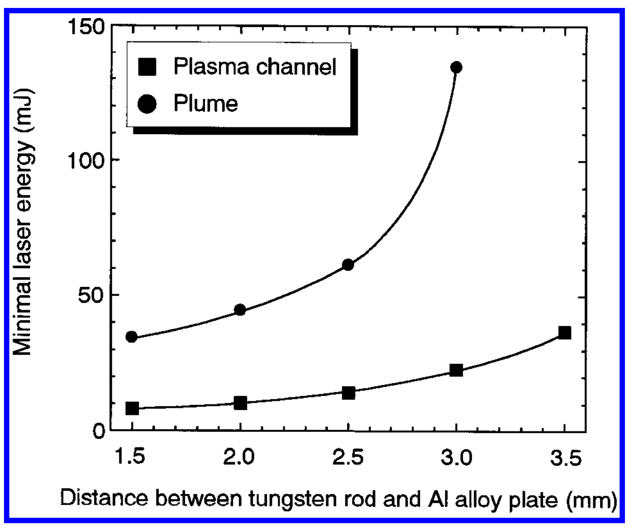


2 Plasma channel between tungsten rod and aluminium alloy plate in argon gas, produced by pulsed laser focusing at laser energy of 23 mJ (optical)

plume method performed in the previous study,[7] the surface of the aluminium alloy plate was placed on the convergent side of best focus of a lens and ablated by the laser beam under the rod.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows a plasma channel with $l_p\approx3·6$ mm. The laser beam was focused at a point 1·8 mm from the laser irradiation spot on the surface at a laser energy of 23 mJ. Figure 3 shows the minimum laser energies required for triggering via the plasma channel and plume methods as a function of distance between the electrodes in the experiments. When the plate was removed, the plasma channel shown in Fig. 2 was not observed. In the absence of the plate, a laser energy of ~60 mJ was required to generate a plasma channel of length 3·6 mm in argon. After the laser irradiation, a crater was produced on the plate. These



3 Minimum laser energies required to trigger arc discharge using plasma channel and plume methods, as function of distance between tungsten rod and aluminium alloy plate

results indicate that reduction of the gas breakdown threshold occurred as a result of laser ablation of the plate. Dust particles in the laser beam path reduced the threshold.[8] Laser ablation of the plate may generate aluminium alloy particles. Reduction of the threshold could be caused by such particles. In this interpretation, the particles produced at an early time during the pulse duration would be required to travel 3·6 mm from the laser irradiation spot on the plate during the pulse length t_L of 7 ns. The required velocity of the particles v_p was estimated to be $5{\cdot}1\times10^5$ m s^{-1}, given by $v_p = l_p/t_L$. The laser irradiation spot was in the shape of an oval, having major and minor axes of 113 and 96 μm, respectively. Laser intensity on the plate was 4×10^{10} W cm^{-2} for the laser energy of 23 mJ. The velocity of the vaporised aluminium produced by the laser ablation at the laser intensity of 2×10^{11} W cm^{-2} was about 1×10^3 m s^{-1} (Ref. 9). Therefore, the laser ablation at the laser intensity of 4×10^{10} W cm^{-2} could not produce particles having a velocity of 5.1×10^5 m s^{-1}. This suggested that the particles did not reduce the threshold. In another possible interpretation, the reduction was caused by a shock wave or the ultraviolet and X-ray radiation from the laser irradiation spot on the plate.[10] It is intended to report more detailed analysis of the plasma channel formation separately since additional measurements are required.

CONCLUSION

It was demonstrated that a plasma channel triggered arc discharge between the electrodes could be employed in a TIG arc welding system. The laser ablation of the aluminium alloy plate reduced the laser energy required to produce the plasma channel. The laser energy required for triggering using the plasma channel was found to be lower than that using the plume.

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REFERENCES

1. R. L. O'BRIEN: in 'Welding processes, welding handbook', 8th edn, Vol. 2, 74–75; 1991, Miami, FL, USA, American Welding Society.
2. R. L. O'BRIEN: in 'Welding processes, welding handbook', 8th edn, Vol. 2, 91; 1991, Miami, FL, USA, American Welding Society.
3. T. TAISAKU: *Weld. Tech.*, 1997, **2**, 81–89 (in Japanese).
4. H. T. BUSCHER, R. G. TOMLINSON and E. K. DAMON: *Phys. Rev. Lett.*, 1965, **15**, 847–849.
5. S. SHIMADA, S. UCHIDA, H. YASUDA, S. MOTOKOSHI, C. YAMANAKA, D. WANG, Y. WATADA, Z. KAWASAKI, T. YAMANAKA, Y. ISHIKUBO and M. ADACHI: *Rev. Laser Eng.*, 1996, **24**, 572–581 (in Japanese).
6. A. J. ALCOCK, M. C. RICHARDSON and K. LEOPOLD: *Rev. Sci. Instrum.*, 1970, **41**, 1028–1029.
7. M. TSUKAMOTO, K. MURAI, M. TANAKA, N. ABE, K. NAKATA and M. USHIO, *Rev. Laser Eng.*, 2003, **31**, 286–288.
8. M. VON ALLMEN and A. BLATTER: in 'Laser-beam interactions with materials', 2nd edn, 124–125; 1995, Berlin, Springer-Verlag.
9. T. YABE: 'Annual collaboration report of Institute of Laser Engineering, 1996', Institute of Laser Engineering, Osaka University, 1996, 219–220 (in Japanese).
10. YU. P. RAIZER: in 'Laser-induced discharge phenomena, studies in Soviet science', 206–212; 1977, New York/London, Consultants Bureau.