2008

Hybrid laser arc welding with high power diode laser

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HYBRID LASER ARC WELDING WITH HIGH POWER DIODE LASER

A thesis submitted in fulfillment of the requirements of
The award of the degree

Doctor of Philosophy (PhD)

UNIVERSITY OF WOLLONGONG

Justino Bernardo Mulima
Msc In Mechanical Engineering

FACULTY OF ENGINEERING
ACKNOWLEDGEMENTS

I would like to acknowledge several people for their assistance and support over the course of the present work. First of all I must thank Prof. John Norrish for technical advice and support whenever needed. I would also like to express my gratitude to Dr. Paul Di Pietro for his invaluable support. Thanks are extended to Dr. Gary Dean, Dr. Dominic Cuiuri, and Dr. Alexander Nicholson who assisted with the experimental design and offered advice whenever needed.

And finally I would like to thank Mr. Joe Abbott, Mr. Greg Tillman and the staff of the mechanical engineering workshop for sharing their expertise on the construction and assembly of the hybrid welding head.
DISCLAIMER

I declare that this work submitted for fulfillment of the requirements for the award of Doctor of Philosophy in the Faculty of Engineering, University of Wollongong is my own work unless otherwise referenced or acknowledged. This thesis has not been submitted for qualifications at any other academic institution.

______________________________
Justino Bernardo Mulima
20/07/08
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NOMENCLATURE

\[ A \quad \text{Wavelength} \]
\[ \Phi \quad \text{Scattering angle} \]
\[ P \quad \text{Mass Density} \]
\[ K \quad \text{Thermal conductivity} \]
\[ \omega \quad \text{Angular frequency of incident beam} \]
\[ H \quad \text{Heat Transfer Thermal Efficiency} \]
\[ R \quad \text{Distance from the particle} \]
\[ \nu \quad \text{Travel speed} \]
\[ \varepsilon_0 \quad \text{Dielectric constant} \]
\[ A \quad \text{Thermal Diffusivity} \]
\[ C \quad \text{Velocity of light} \]
\[ E \quad \text{Electronic charge} \]
\[ c_s \quad \text{Specific heat} \]
\[ n_i \quad \text{Ion number density} \]
\[ m_e \quad \text{Mass of electron} \]
\[ n_e \quad \text{Electron number density} \]
\[ \omega_{pe} \quad \text{Plasma electron frequency} \]
\[ \text{Msec} \quad \text{Micro second} \]
\[ \text{Atm} \quad \text{Atmosphere} \]
\[ \text{Fe} \quad \text{Iron} \]
\[ \text{LnA} \quad \text{Coulomb logarithm} \]
\[ \nu_a \quad \text{Axial Velocity} \]
\[ k_c \quad \text{Concentration factor that depends on radius of the heat source \([1/mm^2]\)} \]
\[ \text{ms} \quad \text{Mil second} \]
\[ ^\circ \quad \text{Degree} \]
\[ \text{Sa/s} \quad \text{Sample per second} \]
\[ T \quad \text{Temperature} \]
\( N \) Particle density
\( V \) Particle Volume
\( Z \) Ion charge number
\( \text{Ar} \) Argon
\( D_L \) Relative Distance
\( Fa \) Measured Fused Area
\( F_L \) Focal Length
\( T_e \) Electron temperature
\( T_P \) Processing Time
\( \text{Hin} \) Process Heat input
\( \{Q\} \) Nodal heat flow vector
\( [K] \) Conductivity Matrix
\( [C] \) Specific heat Matrix
\( \{T\} \) Time derivative of
\( \{T\} \) Nodal Temperature
\( \text{CW} \) Continuous wave
\( \text{CP} \) Combined Process
\( \text{DC} \) Direct Current
\( \text{LP} \) Laser Power
\( \text{PC} \) Personal Computer
\( \text{AWS} \) American Welding Society
\( \text{BOP} \) Bead On Plate
\( \text{CCD} \) Charge Coupled Devices
\( \text{CNC} \) Computer Numerical Control
\( \text{CO}_2 \) Carbon Dioxide
\( \text{CAG} \) Carbon Arc Gouging
\( \text{CTWD} \) Contact Tip to Workpiece Distance
\( \text{DSP} \) Digital Signal Processor
\( \text{DCEP} \) Direct Current Electrode Positive
\( \text{EBW} \) Electron Beam Welding
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<tr>
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<tr>
<td>EPROM</td>
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<tr>
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<td>Flux Cored Arc Welding</td>
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<td>Variable Speed Drive</td>
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<td>Metal Inert Gas</td>
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<tr>
<td>MAG</td>
<td>Metal Active Gas</td>
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<td>LASER</td>
<td>Light Amplification Stimulated by the Emission of Radiation.</td>
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<td>Maximum Permissible Exposure</td>
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ABSTRACT

This work was carried out to address the scope for hybrid laser-GMAW process improvement using controlled dip transfer and a high power diode laser in single and twin spot modes. It is suggested that an optimum combination of the two sources of thermal energy can enhance the speed and quality of single sided butt welds. The objectives of the current work were therefore, to investigate the process control possibilities, performance characteristics and the processes interactions of twin beam hybrid laser-GMAW welding. Since no appropriate twin beam system existed it was also necessary to design and build an experimental system.

This research was made possible by using a power source which enabled flexible computer control of the GMAW current waveform and a 3kW high power diode laser. Weld beads were produced to study the basic operating parameters for the individual arc and laser processes and these were compared with those of combined process with laser in single and twin spot modes. Bead geometry and the current waveforms captured by the data acquisition system were used to evaluate the welding processes performance.

Variables such as groove shape and shielding gas were also found to be critical for full penetration of butt joints on plates. CO₂ produced weld bead with deeper penetration than with Ar based gas mixtures.

A novel hybrid welding head was design and implemented to investigate the process using an extended heat source (as in multicathode GTAW and tandem GMAW) to create an elongated weld pool through the use of laser-GMAW with dual laser spots leading and trailing the GMAW heat source.

To understand the process control mechanisms, a 3D finite element model was created and implemented to analyze the temperature distribution resulting from the arc and mutual effects of the arc and laser heat sources.

**Key words:** Hybrid laser GMAW welding, high power diode laser, enhanced controlled dip transfer