APPLYING LASER-ARC HYBRID WELDING TECHNOLOGY FOR LAND PIPELINES

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ABSTRACT

World demand for natural gas has generated the need for many new land transmission pipelines to be installed in the next decade or so. Although mechanised gas metal arc welding is well developed, there are opportunities for cost savings by using alternative welding processes.

Hybrid Nd:YAG laser - gas metal arc welding enables fibre optic delivery of the laser energy to a robotic welding head to be combined with the addition of extra energy and a consumable to produce good quality, deep penetration welds in a single pass.

The present paper describes initial procedure development to optimise the laser and gas metal arc welding parameters for making joints in pipeline steel. Satisfactory joint quality was obtained and it is intended to develop the process to prototype field trials.

KEYWORDS

Nd:YAG laser, GMAW, Hybrid laser-arc welding, Pipeline steel, Joint Quality

1. Introduction

World demand for natural gas is expected to be satisfied for the next decade or so by the exploitation of current known gas reserves. Many of these reserves, however, are situated in remote locations and there is a need for land transmission pipelines to transport this "stranded gas" from its source to where it is in demand.

As there are large costs associated with laying new pipelines, particularly in remote and possibly hostile environments, very significant gains can be made by identifying and implementing cost savings [1].

The present paper is concerned with hybrid laser-arc welding, which offers opportunities for cost savings.

2. Laser Welding for Land Lay Pipelines

The key processing, production and economic parameters associated with the five candidate welding processes have been reviewed elsewhere [2]. Based on this information, laser welding was chosen for further evaluation. Due to the narrow, deep penetration weld produced, laser welding offers several advantages:

- high joining rates
- low consumable costs
- a reproducible, machine tool welding process
- low manning levels
- low degrees of distortion, leading to greater precision in assembly and reduced rectification

Two main types of laser are available industrially for welding thick section steel - CO_2 gas lasers and Nd:YAG solid state lasers. CO_2 lasers generate light in the infrared regime at a wavelength of 10.6µm and are available at power levels up to about 45kW. The light is transmitted from the laser to the workpiece by a system of mirrors, before being focussed to a small spot for welding. This type of laser is now being used in four European shipyards for different aspects of ship fabrication, where the reduced distortion enables the costs associated with rework to be dramatically reduced. This type of laser has been considered and evaluated for S-lay of offshore pipelines [3].

Nd:YAG lasers, in contrast, generate light at a wavelength of 1.06µm, which is also in the infrared regime, but can be transmitted by a fibre-optic cable. This is a major advantage, as it enables the complex set of mirrors used for the beam path of a CO_2 laser to be replaced by a simple fibre and welding head that can be mounted on a welding robot -figure 1.

Advances in laser technology have led to rapid increases in the power available in Nd:YAG lasers and 4kW Nd:YAG lasers are now extensively used in production. A beam combining unit at TWI enables three lasers to be coupled together to achieve processing capability with up to 10kW.

Initial laboratory trials at TWI to demonstrate Nd:YAG laser welding of a land pipeline were followed by a research programme currently in progress involving BP and CRC-Evans, in which an internal GMAW root run is made using conventional techniques, a laser weld is then made from the outside and a final GMAW capping pass is deposited. A typical weld cross section is shown in figure 2. This approach enables the number of welding stations to be reduced to 3 or 4, whilst maintaining the overall pace of welding to that of the benchmark GMAW process.

Laser welding alone, however, is a demanding process and very tight control of a number of parameters such as fit-up and steel composition is required in order to produce welds of satisfactory quality and performance. Recent attention, therefore, has concentrated on hybrid laser-arc welding, which offers an enhanced range of applicability.

3. Hybrid Laser-Arc Welding

Hybrid laser-arc welding refers to the coupling of the two welding processes into a single process area or weld pool, as depicted in figure 3. The options available include combining either CO_2 or Nd:YAG laser welding with an arc welding process such as gas metal arc welding, gas tungsten arc welding or plasma arc welding.

Compared with the use of laser power alone, hybrid laser-arc welding offers the following benefits:

- increased travel speed or penetration
- improved tolerance to fit-up gap
- ability to add filler material to improve weld metal microstructure, joint quality and properties
- potentially improved energy coupling
- increased heat input, and reduced hardness

There are, however, some drawbacks which include increased process complexity ("more things to go wrong"); additional welding parameters to be defined; and the requirement to define the process parameters anew as these cannot simply be determined from the two separate processes.

Arguably, the most suitable approach for land pipeline welding is to combine a Nd:YAG laser with GMAW because this arrangement offers the opportunity to add filler material combined with fibre delivered laser power. Initial experimental results to develop suitable welding parameters are now presented.

4. Experimental Programme

4.1 Materials

Steel pipe, complying with the requirements of API 5L X-60 and of dimensions 762 mm outside diameter, 15.9 mm wall thickness, was used for this work. The chemical composition of the steel is given in table 1.

4.2 Equipment

A welding system, which integrated the Nd:YAG laser welding head and a GMA welding torch was designed and built. The fixture allowed accurate and repeatable control of the relative positions and orientations of the two heat sources and was mounted on a Kawasaki Js-30 robot, as shown in figure 4.

The laser energy was provided by two Nd:YAG lasers each producing infrared light of wavelength 1.064 µm. The outputs from the two laser sources were fed into a Beam Combining Unit which enabled the combined laser power to be output through a single fibre optic of 1 mm diameter to the welding head which comprised recollimating and focusing lenses configured to produce a spot size of 1.4 mm diameter at a lens to workpiece stand-off distance of 220 mm. The total laser power at the workpiece was 5.2 kW.

The GMA welding system was a Lincoln Electric Powerwave 455, capable of delivering up to 400A welding current. A synergic pulsed welding programme was used.

4.3 Welding Procedure Development

Based on TWI experience and a review of literature, it was considered that the four most important variables were GMA current, arc-laser separation distance, lead process and travel speed. A full-factorial experiment was then designed to assess the influence and interactions of these variables over the following ranges; 150-210A current, 0-4 mm separation and 0.6-0.9m/min travel speed. This resulted in an experimental matrix of 18 welding conditions; the remaining parameters were as in the initial trials i.e. 60° torch angle, 5.2 kW laser power, -3 mm laser focus position, 1 mm diameter wire, 20 mm electrode extension and Ar-18% CO_2-2% O_2 shielding gas. A 1mm diameter Thyssen K-Nova 2% Ni solid filler wire was used. Welds were assessed in terms of depth of penetration and weld flaw level (i.e. porosity and solidification cracking).

5. Results and Discussion

5.1 General Observations

Initial trials showed that the two processes were successfully combined to give stable welding conditions. The degree of spatter was similar to that obtained when using GMAW alone, but the resulting weld beads were wider and less convex than for the GMA process alone. A large, bright plasma was observed, similar to that for the GMA process.

5.2 Weld Penetration

The influences of GMA current and arc-laser separation distance on depth of weld penetration at both travel speeds are shown in figure 5 for the case of the GMA process leading.

In general terms, an increase in the depth of penetration was associated with

- an increase in GMA current
- a decrease in welding speed
- zero arc-laser separation.

The results were in line with expectation and can be explained simply in terms of greater energy density giving rise to greater penetration. At a travel speed of 0.6m/min, the maximum penetration obtained was 7.5 mm; at 0.9m/min the maximum penetration obtained was 6.5 mm.

In the present work, the influence of which process was leading was less significant than the other variables. When the laser is leading the GMA torch is "pushing" and when welding with the GMA process above, "pushing" normally results in reduced penetration. It is clear that further work is required to understand the detailed interactions in the weld process zone.

5.3 Joint Quality

All welds were radiographed and no cracks or planar flaws were detected.

In general, porosity levels were low and satisfied the requirements of BS EN 4515: 2000. The maximum level of porosity found was approximately 0.8% in terms of projected area, which occurred at the slower welding speed of 0.6 m/min. At the higher speed, 0.9 m/min, porosity levels were below 0.4% projected area.

5.4 Joint Hardness

The results of hardness traverses across a hybrid weldment are summarised in table 3. The maximum weld metal hardness was 280HV5 and the maximum HAZ value was 310HV5. As the proposed application is a non-sour environment these values are acceptable.

6. Continuing Developments

The present work formed the initial stages of a continuing programme. Studies are continuing to define a robust welding procedure that will incorporate:

- higher laser powers (~9kW)
- optimisation of joint edge preparation
- all positional welding
- satisfying code requirements for joint quality and properties, in particular hardness and toughness
- grades of steel up to API 5L-X80
- achievement of significant economic advantage over current GMAW practice.

7. Concluding Remarks

- Stable welding conditions were established for the hybrid Nd:YAG laser – GMAW process.
- In the present work, the choice of leading process did not significantly influence the results and maximum penetration (7.5 mm) was achieved at a travel speed of 0.6 m/min, zero arc-laser gap, 5.2kW laser power and 210 A current.
- No cracks were observed and porosity levels were below 0.8% projected area.
- The maximum hardness (310 HV5) was found in the heat affected zone and is below the upper limit for non-sour conditions.
- Hybrid laser-arc welding is a viable process for pipeline welding and further development is continuing.

Acknowledgements

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References

[1] R Espiner "BP's Pipeline Cost Reduction Project" Int. Conf. "New Developments in Land Pipeline" Pipeline Industries Guild, December 2001.
[2] G S Booth and J Hammond "Low cost welding techniques for pipelines", "The Onshore Pipeline Cost Reduction Conference", Pipes and Pipelines International, April 2000.
[3] Gainaud et al "Laser orbital welding applied to offshore pipeline construction" 3rd international conference on pipeline technology, May 2000.

Table 1 Steel Composition (wt%)

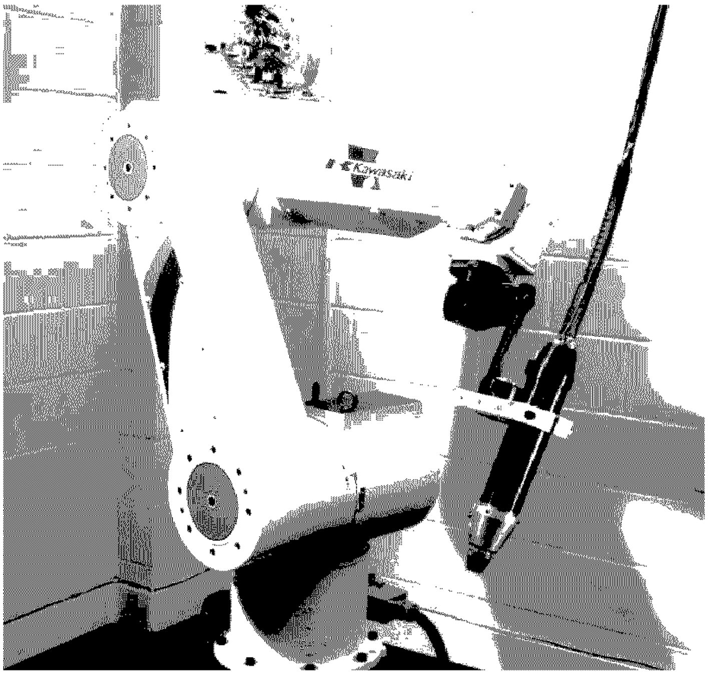
C	S	P	Si	Mn	Ni	Cr	Mo	V	Cu	Nb
0.11	0.004	0.021	0.33	1.42	0.023	0.018	0.003	0.002	0.023	0.040

Ti	Al	B	Sn	Co	As	Ca	O	N	CE
0.003	0.045	0.0003	<0.004	<0.004	<0.004	0.0001	0.0008	0.0032	0.35

Table 2 Summary of hardness survey (hybrid laser-arc welding, GMA current 210A, arc-laser separation 0 mm, travel speed 0.9 m/min.)

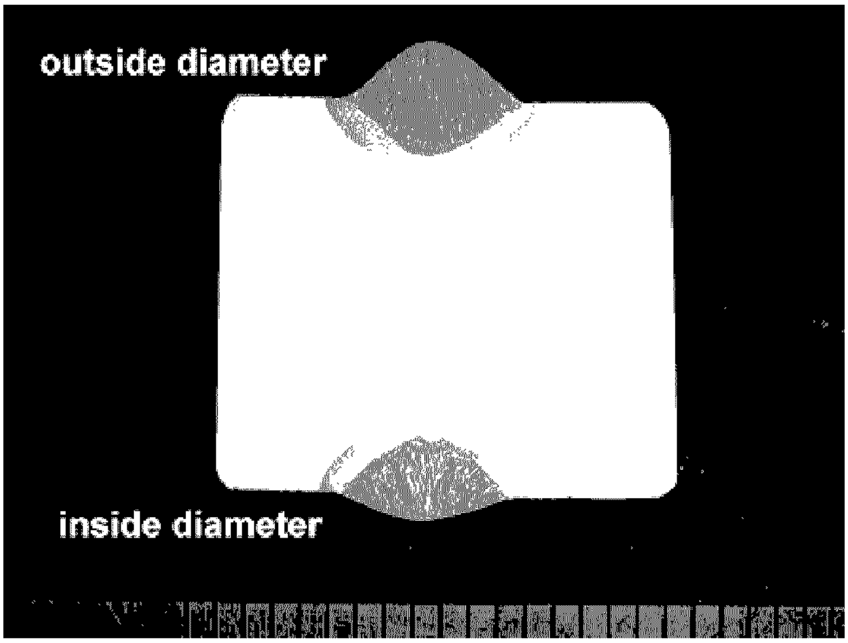
Parent Material HV5	Weld Metal HV5	Heat Affected Zone HV5
164 - 204 (182)	244 - 280 (263)	199 - 310 (250)

Results presented as minimum - maximum / average



(Ref 009795-02)

Fig. 1 Nd:YAG welding head positioned in robot arm, showing fibre delivery capability



(Ref 2000-9-12-9-31-43-002)

Fig. 2 Section through 16mm thick pipe wall, showing internal GMAW root run, laser fill and GMAW capping pass (mm scale shown)

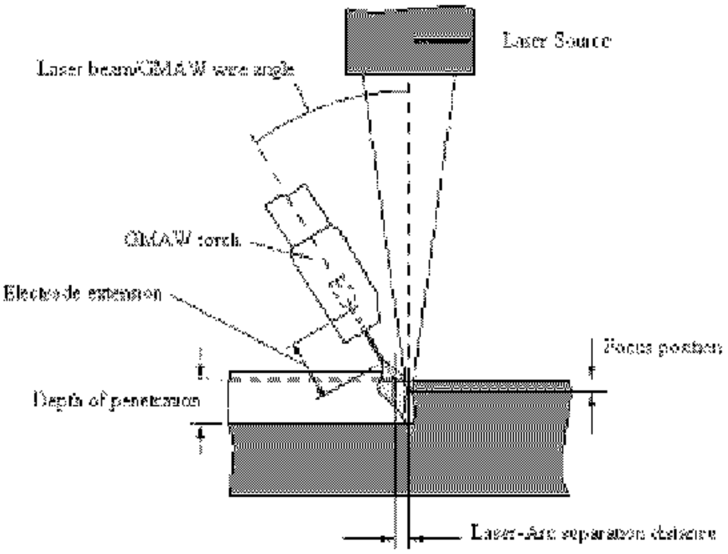
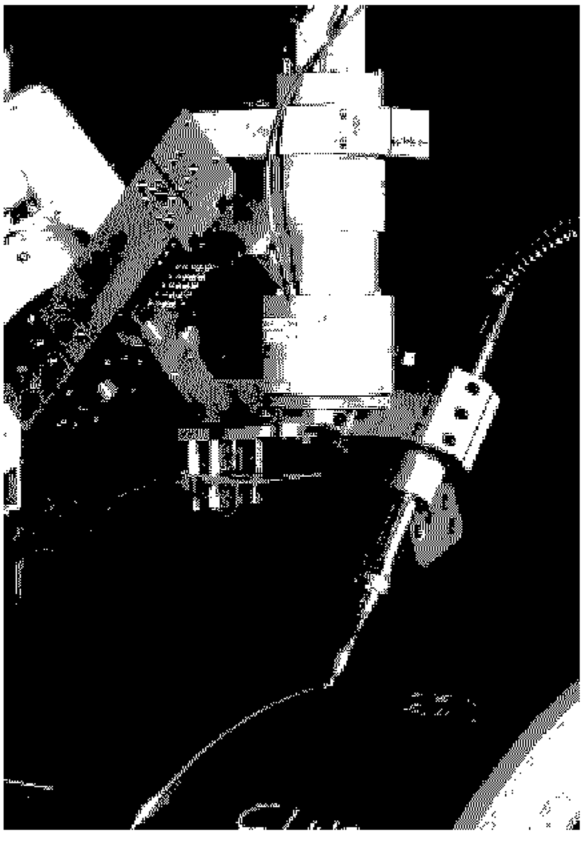


Fig. 3 Hybrid laser-arc welding



(Ref D002316_03)

Fig. 4 Laboratory demonstration of hybrid Nd:YAG laser/GMA welding for pipelines.

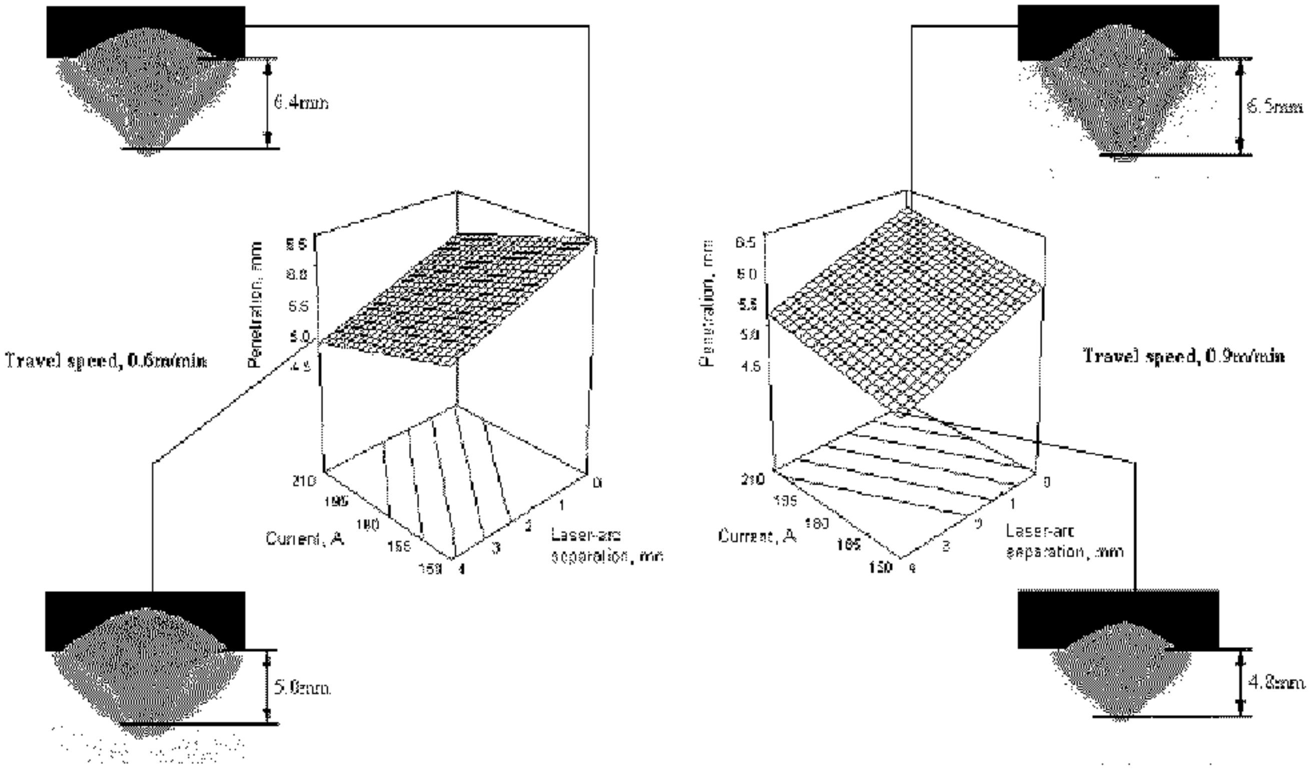


Fig. 5 Influence of welding parameters on weld penetration - **GMA process leading** (Image file D002104)