# Hybrid Laser-Arc Pipeline Welding

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*Installation of new pipelines is predicted to grow at a rapid rate over the next twenty years, due in part to the increase use worldwide of combined cycle power generation plant using natural gas a fuel. The need to construct large diameter pipelines over long distances has led to an increased demand to improve the productivity of pipeline girth welding.*

*Hybrid laser-arc welding using fibre laser offers significant potential for pipeline welding. These new lasers have a very small footprint, together with a high overall efficiency, between 20 and 30%. Hence they can be considered for use in the field.*

*In this investigation, hybrid laser-arc welding of pipeline root runs was evaluated, and it was concluded that acceptable quality root pass welds could be made under a range of welding conditions. Good quality welds were achieved with a laser power of 4 kW and a welding speed of 4 m/min.*

*Laser root / GMAW fill welds in X100 pipeline steel exhibited satisfactory mechanical properties.*

## Introduction

There is a strong trend for increases in natural gas consumption worldwide, which implies continued growth of gas pipeline installation. World gas use is projected to almost double over 24 years, from 90 trillion cubic feet in 2000 to 176 trillion cubic feet in 2025 . High growth over this period is projected for most areas of the world.[1]

The growth is driven both by increasing industrialisation, and also by the increased use of natural gas as a primarily fuel in high efficiency generation of electricity from combined cycle gas turbine plant.

Many gas reserves are far from demand centres, which will result in growth of transportation of gas by LNG (liquid natural gas) carriers, but will also require sustained investment in long distance pipelines.

Worldwide, it is reported that 20,000 km of pipelines were completed in 2003 at a cost of US$15 billion, 60% of which were natural gas pipelines. The materials and labour required for pipeline installation comprise the majority of costs, with 29% of the cost allocated to materials and 49% to labour for land pipelines.[2,3]

In recent years the use of high strength steels has substantially reduced the cost of pipeline materials with X70 and X80 being commonly applied. The planned use of X100 steel will further reduce the tonnage of steel required, since a lower wall thickness is required for a given operating pressure. There has been substantial development work on the issues involved on welding of high strength low alloy X100 steels, and this has led to the capability to place these materials n service.[8] The first X100 section was installed by TransCanada Pipelines in September 2002[4] and long distance pipelines are now being planned using this material.

Mechanised GMAW has now been successfully used for pipeline applications for over thirty years, and has achieved an impressive record on improving productivity over that time. The most widely used mechanised welding technique is the use of a narrow groove welding preparation and solid wire gas metal arc welding, usually with a DC power source. Typically, the laying of the pipe progresses by the addition of a manufactured pipe of either 12 or 24 m length. Thus a new 12 m (or 24 m) section of pipe is aligned with the previous pipe length, and the pipe root run is completed, either from the inside of the pipe using an internal welding machine, or from the outside of the pipe using welding bugs on a band attached to the pipe.

**Figure 1: Welding sequence during pipeline construction**

Once the root run has been completed, a new length of pipe can be added. The remaining fill runs are then completed by a number of welding stations, and typically each welding station is used to complete a specific pass, until finally the weld preparation is filled, and the completed weld can be inspected. The rate of welding the root run determines how fast the pipeline can advance, and the number of fill passes determines the amount of equipment and labour required to fill the weld preparation.

Research at Cranfield University over the last several years has led to the development of "CAPS", the Cranfield Automated Pipe

Welding System. CAPS utilises two tandem welding torches, and hence four welding wires are being used simultaneously. This results in a fourfold increase in weld deposition rate, and welding travel speeds up to 1.5 m/min. On a typical pipe line spread, this can reduce the number of fill pass welding stations from 16 down to 4, with consequent large savings in equipment and manpower.[5] The CAPS system has now been adopted by pipeline contractors, and will be used on commercial projects in 2006.

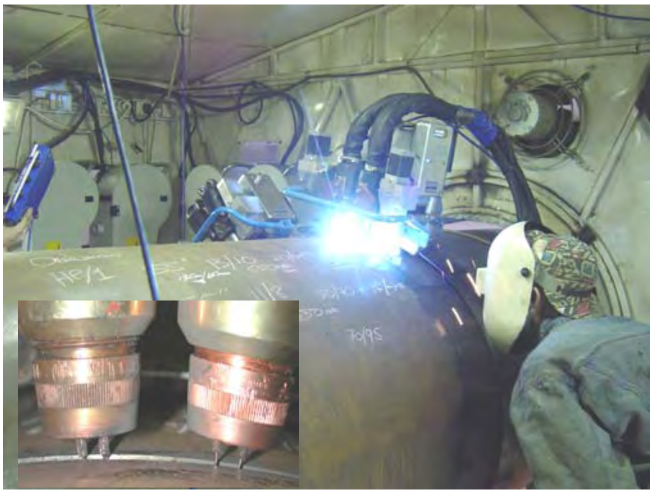

**Figure 2. Arrangement of CAPS welding torches and system mounted on RMS welding systems mechanised welding bug.**

The economics of pipeline construction are thus determined by two aspects of the pipeline welding method:

- The root pass welding speed governs the overall productivity of the pipeline construction spread,
- The fill pass welding deposition governs the number of welding stations needed to maintain pace with the root pass.

Previous development work has generated the potential of substantial cost savings from the use of high strength steels, combined with the high productivity fill pass techniques that have been described. The remaining area where improvements are possible is in welding of the root run. It has been recognised for some time that it should be possible to use lasers to enhance pipeline welding productivity[6], and indeed to trials have taken place in the past using $CO_2$ laser welding.[7] In practice, solid state lasers with fibre delivery are likely to provide systems that could be used in the field, and the recent developments in fibre lasers offer the potential to make laser or hybrid laser-arc root runs, together with an overall process efficiency that is practical for field use.

In practice, it takes between two and three minutes to assemble and align a new pipe length before welding. Hence there are benefits to be gained by reducing the root welding time to about one minute, but there is little benefit in reducing this time further. Thus, for a 1.25 m diameter pipeline, a reasonable target for welding speed is about 4 m/min.

The objective of this project was to achieve welding speeds of up to 4 m/min for laser and hybrid laser-arc welding of pipeline root runs. The use of laser welding for pipeline root welds together with high productivity GMAW fill offers the benefits that high welding speeds and high pipeline lay rates can be achieved while still providing control over weld and heat affected zone properties, with a weld geometry for which there is already extensive experience in industry.

### Fibre laser welding of pipeline steels

In this initial phase of work on laser welding of pipeline steels, three sets of experiments were conducted:

1. Initial characetrisation of penetration and microstructure for laser only welds on X100 steel.
2. Investigation of root run quality versus welding parameters for hybrid laser-arc root run welds, using 6 mm thick C-Mn steel
3. Enlauation of weld quality and mechnical properties of laser root / GMAW fill welds on in 19 mm thick X100 pipleine steel.

Initial laser bead-on-plate runs were conducted on 19 mm thick API 5L GradeX100 pipleine steel in the flat position. This pipeline steel has a composition of 0.06%C, 1.9%Mn, 0.49%Ni, 0.26%Mo, 0.3%Cu and has been subjected to thermo-mechanically controlled processing (TMCP) to acive a minmum tensile strength of 690 MPa (100 ksi). The high power fibre laser used was an IPG YLR-8000 system with a nominal maximum output power of 8 kW, an emission wavelength of 1070 nm, and a beam parameter product (BPP) of 16 mm.mrad. The Precitec final lens had a focal length of 250 mm, and the delivery fibre has a core diameter of 300 μm. The experimental set up adopted is shown in Figure 3. The Precitec lens assembly is mounted on a Fanuc M-710iB/45T robot.

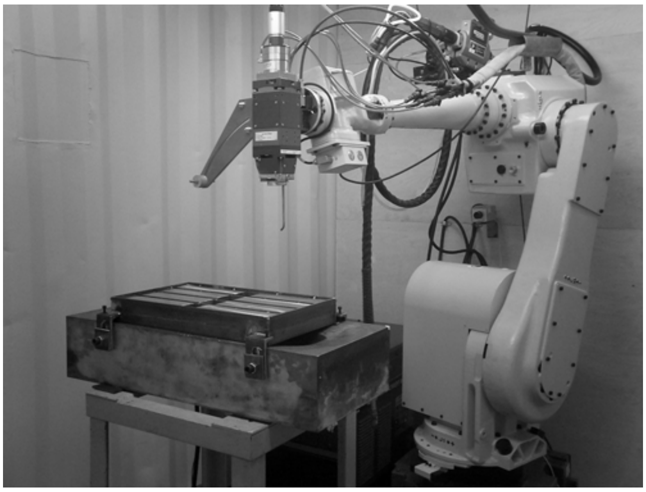

**Figure 3. Experimental set-up for welding of pipe steel in the flat position.**

A set of experiments was designed with four levels of laser power (from 2000W to 8000 W) and over a range of travel speeds up to 8 m/min. The focal point was kept constant on the specimen surface. Argon was used as assist gas at a flow rate of 11 l/min. All other processing parameters were kept constant.

Figure 4 shows the penetration depth versus travel speed for the four levels of laser power.

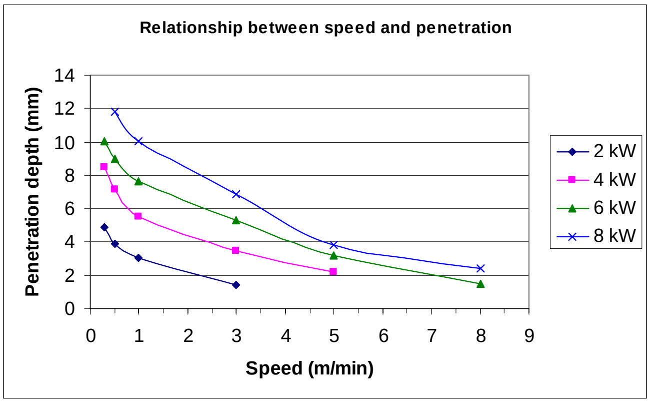

**Figure 4. Laser weld penetration depth in X100 plate**

Laser-arc hybrid welding was used in the second series of experients to investigate the relationship between weld preparation shape and welding parameters. A Lincoln Power Wave 455M/STT power supply was used in conjuction with the IPG YLR-8000 laser. A simple "V" preparation was used for root run trials, as shown in Figure 5.

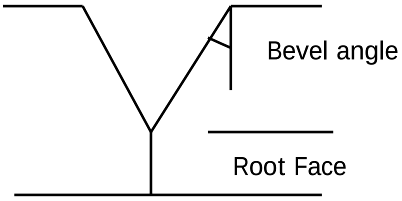

**Figure 5. Weld preparation for root run trials.**

Weld preparation geometry and welding parameters were varied as follows:

| | |
|---|---|
| Laser power: | 4 to 6.75 kW |
| Focus Point: | Plate surface +0 /-2 mm |
| Wire feed speed | 10 to 15 m/min |
| Arc power: | 5 to 7.5 kW |
| CTWD: | 12 to 17 mm |
| Bevel angle: | 12°, 18°, 45° |
| Root face: | 0, 1, 2, 6 mm |
| Laser/arc distance: | 2 to 5 mm |
| Laser / torch angle: | 19° |
| Wire diameter: | 1 mm |
| Plate thickness: | 6 mm |
| Shielding gas: | Argon |

CTWD = Contact tip to work distance.

It was possible make high quality root runs at 4 m/min over a range of conditions, indicating a reasonable degree of tolerance to variations in welding parameters.

Accepetable welds were made using the following conditions:

| | |
|---|---|
| Laser power: | 5 kW to 6.25 kW |
| Bevel angle: | 12° |
| Root face: | 1 mm |
| CTWD: | 14 mm |
| Laser / arc distance: | 2 mm |
| Wire feed speed: | 10 to 12.5 m/min |

Good welds were also made at a laser power of 4 kW with a 0 mm root face and a bevel angle of 18°

Figure 4 shows a typical example of a root run weld made at 4 m/min, laser power 6.25 kW, wire feed speed 10m/min

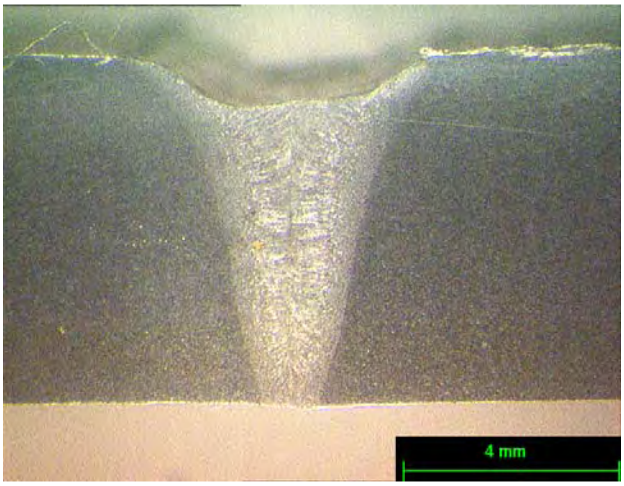

**Figure 6. Hybrid laser-arc root run weld in 6 mm plate**

In the third series of experinets, laser root welds were made with increased root face thickness and a lower welding speed of 1.5 m/min using the X100 plate discuused earliuer. The weld preparation shown in Figure 7.

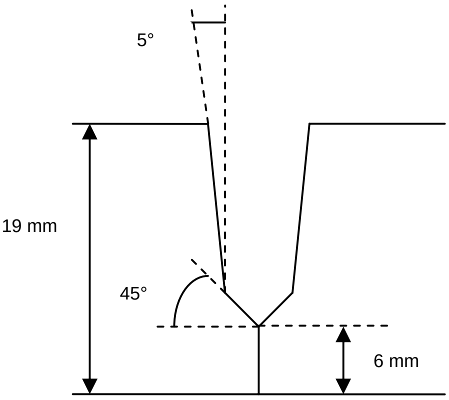

**Figure 7. Weld preparation for laser root/ GMAW fill welds in X100 plate**

The welding parameters were as follows:

| | |
|---|---|
| Laser power (root run): | 7.6 kW |
| Pre-heat: | 100°C |
| Root run speed: | 1.5 m/min |
| Shielding gas: | Argon or Trimix |

4 Tandem pulsed GMAW Fill passes

| | |
|---|---|
| Lead Wire feed speed: | 14.5 m/min |
| Trail wire feed speed: | 14.5 m/min |
| Mean Welding current: | 233 amps |
| Mean welding voltage: | 24 volts |
| Welding speed: | 1.5 m/min |
| CTWD: | 13.5 mm |
| Pre-heat: | 100°C |
| Shielding gas: | Trimix |
| Filler wire: | 1 mm dia. Carbofil NiMo1 |

Completed welds were free from defects, and a smooth root profile was achieved. A weld made with Argon shielding for the laser root run is shown in Figure 8.

**Figure 9. Laser root/GMAW fill weld in X100 plate**

A detailed evaluation of mechanical properties was completed for these welds.

Hardness traverse results are shown in Figure 10. Since these measurements are taken along the weld centre line, they are, as ecxecetd, similar to results previously obtained in X100 material by Hudson.[8]

Charpy test reslts are shown in Figure 12. The Charpy V notch was placed in the root (laser welded) region. Again, the Charpy test results are very similar to those of Hudson.

The GMAW weld comprises the majoity of the weld volume, and hence it is not surpising that the mechanical properties are similar to those of wleds made with a GMAW root.

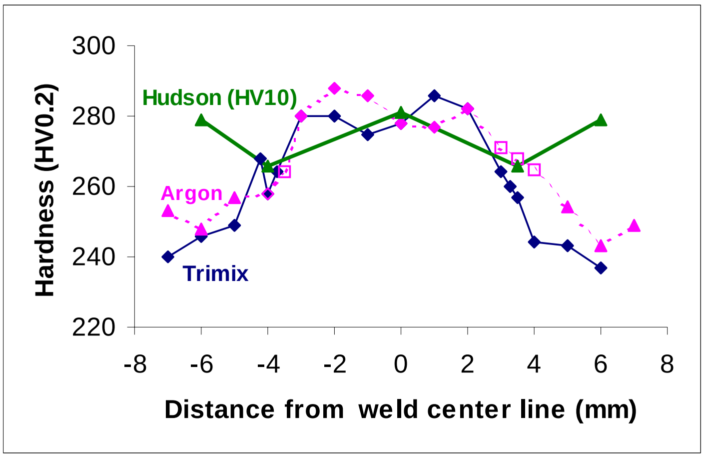

**Figure 10. Hardness traverse, weld centre line. Laser root, GMAW fill, X100 plate**

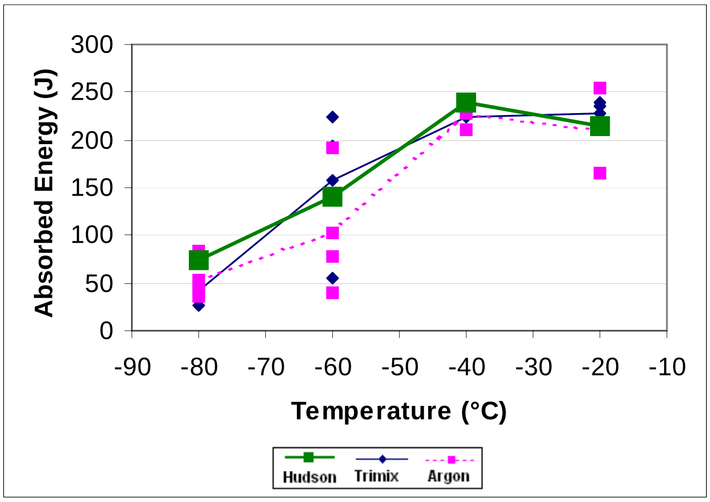

**Figure 12. Charpy test results, laser root,GMAW fill, X100 plate**

## Conclusions

- Acceptable root pass quality can be achieved in pipeline root pass welds over a range of welding conditions using hybrid laser-arc welding
- Satisfactory laser-arc welds were made at a laser power of 4 kW and a speed of 4 m/min. This welding speed provides a significant increase over typical welding speeds achieved for GMAW root runs (up to 1.5 m/min), and meets the target set in this project for pipeline root welding speed.
- High quality laser root / tandem GMAW fill welds made at a welding speed of 1.5 m/min showed mechanical properties (hardness and toughness) very close to GMAW root welds made under similar conditions.

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