Recent Developments in High Productivity Pipeline Welding

D. Yapp and S. A. Blackman
Welding Engineering Research Centre
Cranfield University, Cranfield,
Bedfordshire, MK43 0AL
United Kingdom
d.yapp@cranfield.ac.uk
s.blackman@cranfield.ac.uk

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.

Many novel techniques have been tried in the past to achieve productivity gains, including laser welding, flash butt welding, homopolar welding, and radial friction welding. In spite of the failure to gain wide acceptance, there is still current development aimed at achieving their eventual implementation.

Single wire mechanised gas metal arc welding (GMAW) remains the dominant pipe girth welding technique, and has been optimised in the past to produce the maximum productivity possible with this process. Continued development of GMAW with dual torch, tandem GMAW welding and novel techniques for GMAW roots is leading to further significant gains in arc welding productivity.

This paper describes a new development, the CAPS project, (Cranfield Automated Pipe-welding System), where tandem GMAW in a narrow groove has been applied to pipeline girth welding with two tandem torches in a single welding head. The CAPS system offers welding productivity three to four times higher than that possible with the conventional single wire GMAW technique, while still producing a weld which is very similar to that generated by single wire welding. The development of the system is described, as well as recent successful trials under field conditions.

The development of high power lasers has spurred a current high level of interest in the possibility of application to pipeline welding, and current research is described in which the feasibility of pipeline laser welding has been established.

Keyword: Welding, GMAW, pipeline, productivity

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:

Region	Project growth in gas consumption from 2001 to 2025, trillion cubic feet
Eastern Europe / Former Soviet Union	23
North America	19
Developing Asia	14
Western Europe	12
Central and South America	8

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. Pipeline projects planned to complete in 2004and beyond totalled 41,000 km.

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.

The capital cost of pipeline projects is governed by right-of-way access and preparation; material costs; alignment, welding, NDT and coating costs; and, reinstatement costs. In recent years the use of high strength steels has substantially reduced the cost of pipeline materials with X70 and X80 being commonly applied and the first X100 section installed by TransCanada Pipelines in September 2002. There has been much research interest in this area and it is expected that the further use of X100 will provide further cost reduction. However, alignment, welding, NDT and coating costs typically represent around 20% of the total pipeline cost and there has been little technical progress in this area since mechanised GMAW was introduced in 1969.

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. Over the same period, there has been significant investment in “one-shot” and power beam processes in the attempt to achieve increase in productivity compared to GMAW, but despite extensive development efforts, these processes have so far failed to achieve widespread benefits for pipeline construction applications. Flash-butt welding has been the most widely applied one-shot welding process and it is still being promoted by the Paton Institute. However, there have been no recent developments in the process and it is not widely used outside of Russia and the Ukraine. Despite its lack of success, one-shot welding research still continues with MIAB and induction welding currently being investigated again. Recent research into Nd:YAG laser welding of pipelines has shown some promise but the size and energy requirements of Nd:YAG lasers prevent their use in the field. New developments in laser technology do show some promise with better beam quality and better efficiency than Nd:YAG lasers. These may be applied to pipeline applications in the future.

Presented at COBEF 2003 – II Brazilian Manufacturing Congress, 18-21 May 2003, Uberlândia, MG. Brazil.
Paper accepted October, 2003. Technical Editor: Alisson Rocha Machado.

Whilst some companies have invested large sums in one-shot and power-beam welding processes and failed to see a return on investment, others have found that relatively low cost developments in mechanized GMAW and FCAW have significantly increased welding productivity and reduced repair rates. With the recent introduction of digitally controlled electronic welding power supplies, a range of novel arc welding techniques have also been developed. In the short term, it is believed that some of these novel arc welding techniques offer the best potential for cost-reduction in pipeline applications.

Developments in Gas Metal Arc Welding

The mechanised GMAW process is currently the most widely used welding process for large diameter transmission pipelines and there have been a number of recent welding procedure developments that have improved productivity. In addition to extensive use onshore and for S-lay, it has been proven suitable for J-lay installation. The GMAW process therefore represents the current state-of-the-art and represents the benchmark against which other welding processes have been assessed.

The economics of pipeline construction are 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.

Ongoing research is investigating novel processes that address each of these areas.

Developments in GMAW Root Pass Techniques

A high integrity root bead with a smooth internal profile is essential in girth seams of gas and oil pipelines. The root run is generally the rate controlling process in transmission pipeline construction and the welding is normally performed using an internal welding machine or an internal line-up clamp with copper backing. Both of these systems have been demonstrated to provide adequate welding production rates for most pipeline applications. However, in the case of small diameter pipe and closing seams in larger diameter lines the use of internal welding systems is impossible and single sided, external approach must be adopted. In manual welding this is accomplished by using a 'keyholing' technique with a cellulosic electrode but until recently the only reliable alternative for GMAW was the use of an internal backing system. Earlier work by one of the authors indicated that controlled dip transfer could be used to deposit high integrity root runs in thin wall pipe. This work indicated that controlled dip transfer enabled excellent control of penetration and freedom from lack of fusion defects. A typical macro-section of a root run is shown in Figure 1. Full pipe welds have been made and procedures have been developed and qualified for X80 pipe based on this controlled transfer root and pulsed transfer fill passes. The process tolerances for lack of fusion were fully explored over a wide range of heat inputs.

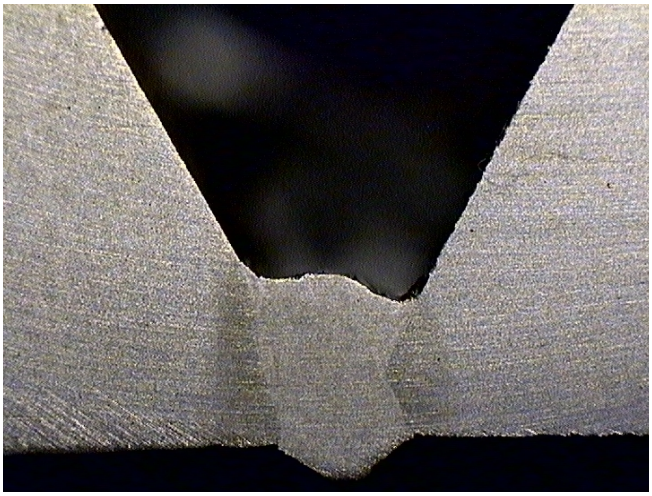

Figure 1. Root run in X80 pipe made using a controlled dip process.

The process operating envelope was found to be very large and attempts to generate lack of fusion defects in these welds failed unless the welding torch was significantly displaced from the centreline of the weld. It was found however that while the process was tolerant to the expected levels of mismatch and gap width the optimum operating envelope was dependent on travel speed and the optimum speed of 390mm/min was felt to be relatively slow. Whilst the process can be shown to achieve the required integrity a multi-head external bug is required to achieve the required productivity.

To address this limitation a novel high speed root run technique has been developed. The technique, known as 'Synchrowire' allows controlled penetration root beads to be made at speeds of up to 1200mm/min. A typical weld bead is shown in a standard 'V' bevel in Figure 2.

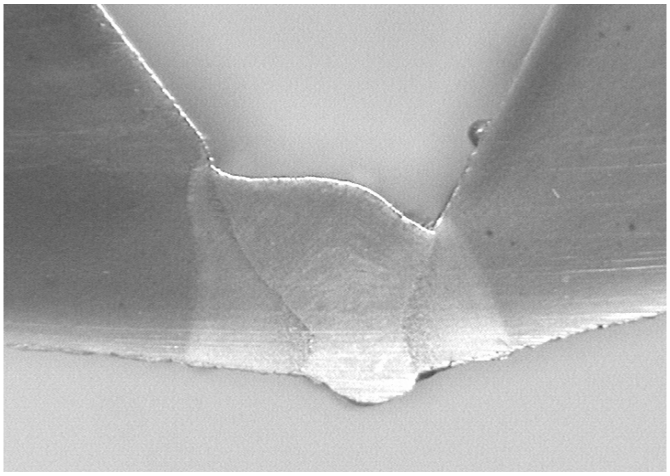

Figure 2. Synchrowire GMA weld in 8mm X80 plate.

The technique requires the use of a high quality wire feed system and a controlled transfer power source, further work is currently underway to assess the process tolerances and suitability for narrow gap joint designs and closed butt preparations.

An alternative approach is the use of variable polarity GMAW. The Edison Welding Institute (EWI) in Columbus, Ohio, USA has recently been investigating variable-polarity GMAW and has performed limited root pass welding trials on pipe. They were able to produce a root pass without backing at travel speeds of 1.5m/min, Figure 3.

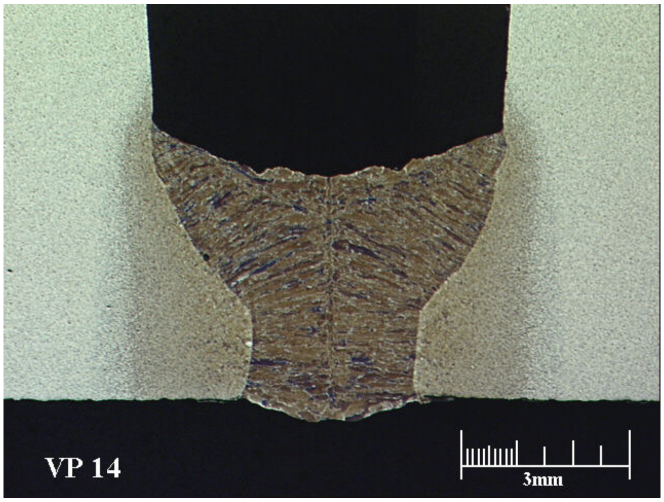

Figure 3. VP-GMAW root pass.

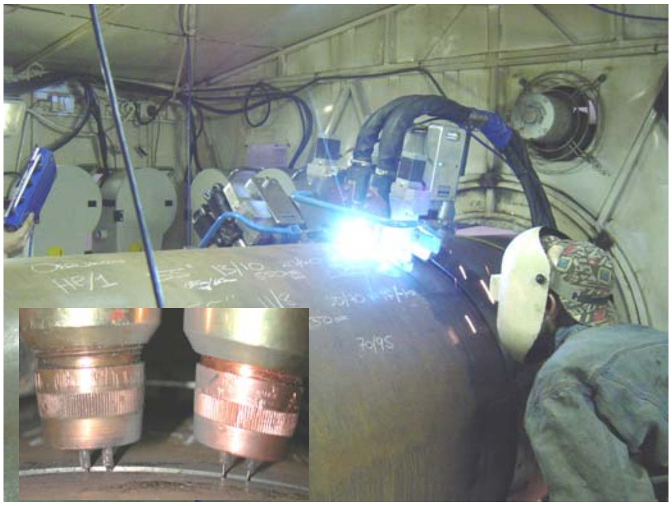

Figure 4. Arrangement of CAPS welding torches and system mounted on RMS welding systems mechanised welding bug.

High Deposition GMAW Fill Pass Developments

Although the fill passes do not control progress of the pipeline construction, the efficiency of fill and cap processes determines the overall joint completion rates and the number of fill stations required. They take on increasing significance as the pipe wall thickness and diameter increase. The economic viability of many future projects depends on the ability to complete the fill passes with as small a pipeline spread as possible in order to reduce labour and equipment costs. Developed in 1969, the original GMAW mechanised welding systems utilised a single torch and wire feed. Serimer Dasa's Saturnax welding system was the first mechanised GMAW equipment to successfully use dual torches for pipeline construction. This welding head requires less welding stations as it deposits two passes simultaneously and it has been used extensively onshore and offshore. Several pipeline contractors now offer dual-torch welding equipment although single-torch systems still remain the most widely used.

With funding from BP Exploration and TransCanada Pipelines, Cranfield University's Welding Engineering Research Centre have been developing dual-tandem GMAW to further reduce the number of fill and cap welding stations required and their CAPS (Cranfield Automated Pipewelding System) has now been successfully field tested at RMS Welding Systems in Canadian winter conditions.

Tandem GMAW differs from conventional GMAW as two welding wires are passed through the same welding torch. A single torch with two contact tips is used to feed both wires into a single weld pool. Although the potential of the multi-wire GMAW process was first explored as early as the 1950's, it has not become commercially viable until relatively recently due to performance limitations associated with the power source technology, that resulted in process instabilities. However with the advent of modern microprocessor-controlled inverter power sources and an improved understanding of metal transfer characteristics, tandem GMAW is now being successfully applied in many industries.

The Cranfield Automated Pipewelding System (CAPS) uses two tandem torches on a single carriage (dual-tandem welding) Figure 4. The tandem GMAW allows high welding speeds and two passes are deposited simultaneously which further reduces welding times. This results in a significant reduction in the number of welding stations required to achieve a given number of welds per day and this leads to major savings in labour and equipment costs. In comparing welding systems for a recent project estimate, CAPS resulted in a 25% saving in girth welding costs when compared with conventional mechanised GMAW systems.

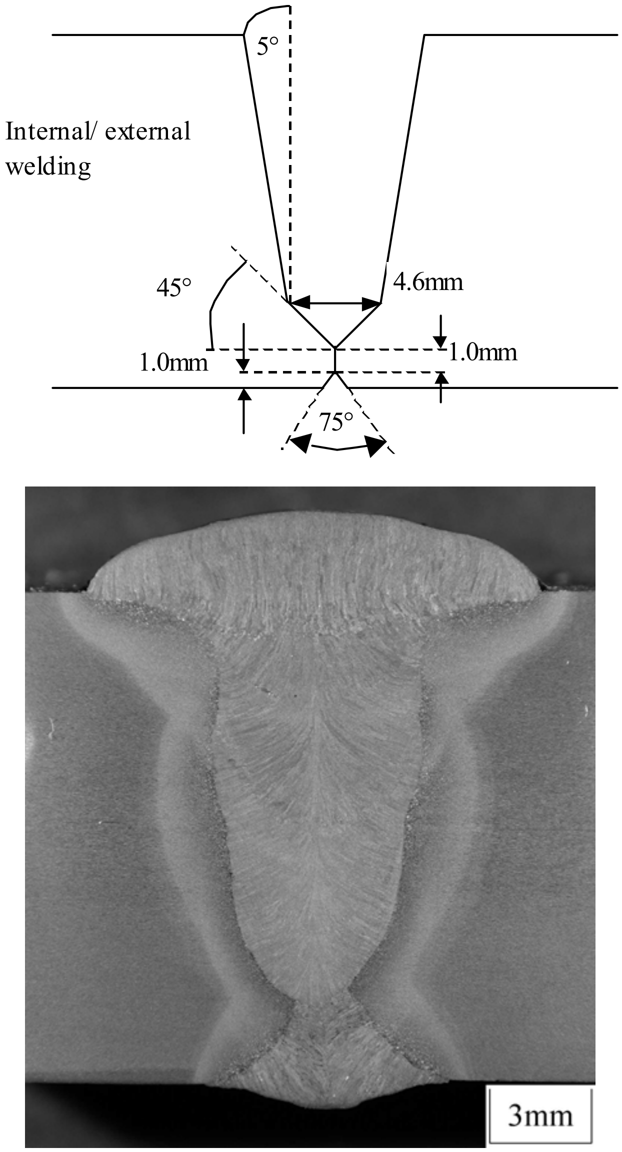

Figure 5. CAPS weld bevel and macro-section from weld in 14.9 mm wall X100 linepipe.

A major benefit of CAPS is that it has evolved from existing technology. As seen in Figure 5, the completed weld has a similar weld bevel and profile to conventional mechanised pipeline welds so conventional radiography and automated ultrasonic testing can be used for defect detection. The suitability of automated ultrasonic testing was demonstrated during the CAPS field trials. The weld metal microstructure and metallurgical properties are also similar to conventional mechanised pipeline welds. CAPS is therefore suitable for use on all linepipe materials including X80 and X100 steels and the system does not therefore require any regulatory approval and can be implemented under normal codes and standards. From 3-13th March 2003, the CAPS equipment was field tested in Edmonton, Alberta, Canada. BP Exploration provided funding and Cranfield worked with RMS Welding Systems to complete the field trials. These were performed on 40”x19.1mm X80 linepipe. Table 1 shows mechanical test results for the dual-tandem GMAW weld procedure. The procedures was qualified with a 1%Ni, 0.3%Mo welding consumable to ensure overmatching criteria was satisfied. Despite the high strength levels, excellent Charpy Impact and CTOD properties were obtained.

Table 1. Mechanical test data for CAPS field trial weld procedure.

All Weld Tensile Test	**Rp0.2 (MPa)**		**Rm (MPa)**		**Yield / Tensile Ratio**		**A (%)**	
	753		810		0.93		23	
Charpy Impact, 10x10mm, -20°C, J	**Weld Metal Cap**		**Fusion Line Cap**		**Weld Metal Root**		**Fusion Line Root**	
	210, 197, 210 (206)		243, 244, 244 (244)		317, 298, 202 (272)		250, 250, 228 (243)	
CTOD -10°C, mm	**Weld Bx2B**		**HAZ-50% Bx2B**		**HAZ -15% Bx2B**		**Weld Root BXB**	
	0.555(δ_m) 0.571(δ_m) 0.615(δ_m)		0.624(δ_m) 0.629(δ_u) 0.107(δ_c)		0.336(δ_u) 0.546(δ_u) 0.677(δ_m)		1.756(δ_m) 1.784(δ_m) 1.268(δ_m)	
Cross Weld Tensile Tests	613 MPa		621 MPa		617 MPa		618 MPa	
	Parent Metal Fracture		Parent Metal Fracture		Parent Metal Fracture		Parent Metal Fracture	
Nick Break Tests	Pass		Pass		Pass		Pass	
Side Bend Tests	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Max Hardness $HV_{0.5}$	Parent Cap	FL Cap	Weld Cap	FL Mid	Weld Mid	Parent Root	FL Root	Weld Root
	235	288	334	259	307	232	279	255

Figure 6 and Figure 7 show cooling curves for a variety of different pipeline welding processes. Each weld was made at the same calculated arc energy and the curves have been adjusted to align the 1400°C point on each curve. Figure 6 was produced from a thermocouple plunged into the weld pool. It can be seen that the tandem GMAW process with one welding torch has the same cooling rate as the single GMAW torch. For the dual-torch and dual-tandem processes, the thermocouple was plunged into the weld pool of the second welding torch. Figure 7 shows the traces obtained from a thermocouple embedded in a drilled hole immediately under the welding pass being deposited. The traces clearly show the effect of the second welding torch. In the case of dual-tandem GMAW, although the heat input was the same as dual-torch GMAW the travel speed was double and so the second torch passes a given point quicker than in the dual-torch process. This has a tempering effect on the weld metal. The CAPS field trials were welded with a welding consumable that Cranfield had previously used for X100 welding and was used in the 1km length of X100 installed by TransCanada in 2002. Table 2 shows the difference in all-weld tensile strength between a single torch and dual-tandem weld made with this consumable. This reduction in strength due to the cooling cycle of the first weld deposit being extended by the heat of the second weld deposit makes it difficult to qualify overmatching weld procedures for X100 but this has been done by Cranfield University. This tempering effect may be interesting for in-service pipeline applications such as reclamation by weld deposition and this is an area that Cranfield are investigating further.

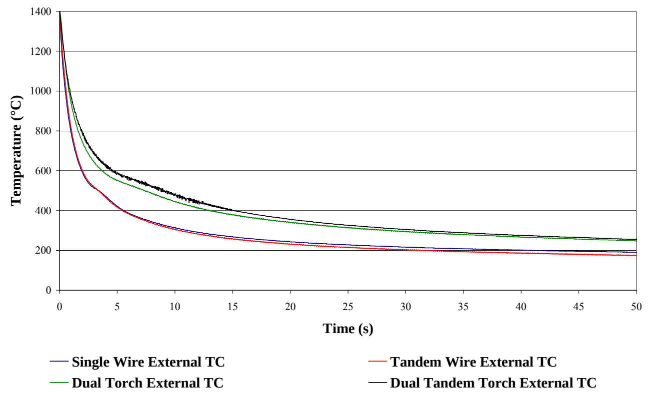

Figure 6. Cooling curves for an external plunged thermocouple with various GMAW pipeline welding systems.

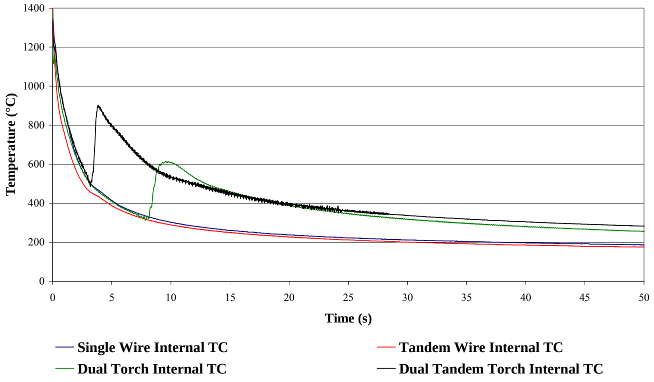

Figure 7. Cooling curves for an internal thermocouple with GMAW pipeline welding systems.

Table 2. Comparison of all weld tensile data for single and dual-tandem GMAW.

Weld Type	Rp0.2 (MPa)	Rm (MPa)	Yield / Tensile Ratio	A (%)
Single Torch Narrow Gap internal/external 1.0%Ni/ 0.3%Mo	841	888	0.95	20.5
CAPS Dual Tandem Narrow Gap internal/external 1.0%Ni/ 0.3%Mo	753	810	0.93	23

The CAPS field trials were completed successfully and the potential of the system clearly demonstrated. There were some teething problems with the power sources operating outdoors in the cold environment and some minor problems with the welding carriages but the arc stability was excellent and welds acceptable to AUT were produced. It is hoped that the system will be used on a pipeline in the near future.

Cranfield are undertaking further trials to improve the performance of the CAPS process. Currently, the second welding torch uses lower wire feed speeds than the first because it is welding onto hot material and too much hot material cannot be supported in position. It is hoped that the use of variable polarity tandem GMAW on the second welding torch will allow higher deposition rates and Lincoln Electric have manufactured a prototype power source for Cranfield. Cranfield are also working with EWI and the University of Wollongong to develop adaptive control techniques for the CAPS process.

Developments in Laser Welding

CO_2 Laser Welding Developments

CO_2 lasers have a wavelength of 10.6 μm and this is not transmittable through glass. Hence, to transfer the beam from the laser source to the workpiece, a series of mirrors must be used. This makes it difficult to use CO_2 lasers for circumferential welding but one system has been field tested by Bouyges Offshore. Bouyges Offshore developed a full production welding system based on a 12 kW laser and this has been installed and tested on the DLB BOS355. The system was used to weld six 0.5 km sections of a 10” x 12.7 mm API 5L X52 pipeline in the 5G position. All of the equipment is containerised and designed to be easily transported and installed on different pipelay vessels. With filler metal additions, the process was tolerant to a maximum gap of 0.5mm and a maximum internal misalignment of 2mm.

French company, AXAL, have developed a prototype J-lay welding system suitable for lasers up to 20 kW (PCT World Patent Application WO 98/06533). CRC-Evans Automatic Welding have taken patents for internal/external laser welding of pipelines (US Patents 5796068 and 5796069) but these cover concept design and equipment has not been built or tested.

Nd:YAG Laser Welding Developments

The most important aspect of Nd:YAG lasers is the 1.06 μm wavelength of the beam which can be transmitted through a fibre optic cable. This makes it much easier to automate high speed welding of complex geometries and the recent ability to produce high power Nd:YAG laser beams made them attractive for pipeline applications. 4 kW Nd:YAG lasers are the largest commercially available but it is understood manufacturers have the capability to produce a 6 or 8kW Nd:YAG laser if there was a demand. Another method of producing a higher effective beam power at the work piece is to combine the beams from multiple Nd:YAG lasers.

Cranfield, EWI and TWI have been investigating the potential of laser welding of pipelines for the last three years. EWI and Cranfield worked on a project for Pipeline Research Council International and TWI worked on a project funded directly by BP Exploration. EWI, TWI and Cranfield have then all collaborated on research for a group of sponsors in the “YAGPIPE” project. All three projects have shown that hybrid Nd:YAG laser – gas metal arc welding of the root pass has the potential to increase welding productivity.

Laser root welding may replace the IWM or copper ILUC and be used with single, dual or CAPS GMAW fill passes. A typical macro photograph of such a weld is shown in Figure 8. EWI and TWI have produced 3mm root passes at 3m/min and 3.5m/min using 3kW and 6kW of laser power respectively.

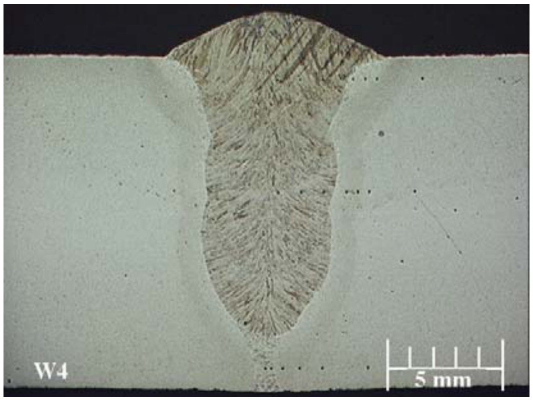

Figure 8. HL-GMAW root with GMAW fill.

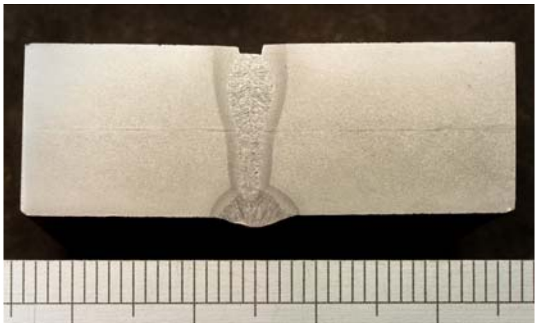

Figure 9. IWM root pass with HL-GMAW first fill.

HL-GMAW may also be used to produce the first fill pass after completing an internal root using an IWM as shown in Figure 9. TWI has been able to weld 8mm thickness at 1.0 m/min using 7kW of laser power. A variation of this is the deep penetration root/fill pass that is completed after the root pass of an IWM but fully penetrates through it to avoid centreline defects. TWI has been able to use 9kW of laser power to weld 12mm thickness at 1.0m/min.

EWI and TWI have demonstrated that there are potential production benefits from the use of Nd:YAG lasers. However, due to wall plug efficiency, physical size and cooling requirements Nd:YAG lasers are not considered suitable for onshore pipeline applications although they could possibly be considered for a laybarge. This was known at the start of the YAGPIPE project and it was assumed that new laser technologies would develop over the course of the project and that these may be suitable for pipeline applications. Currently, the two most promising options are diode lasers and fibre lasers. Both have relatively high wall plug efficiencies and small physical size. Both could also be transported on the right of way.

Diode laser technology is developing quickly. Diode lasers are over 30% energy efficient and their operating cost is less than 50% of Nd:YAG lasers. Diode lasers are solid state devices so easily transportable and would be ideal for pipeline applications. Unfortunately, diode lasers have so far not had the beam quality to allow keyhole welding and they have therefore generally been used in the conduction welding mode only. Diode laser manufacturers are working to increase power and improve beam quality and recent work has shown that energy densities over 2.5×10^5 W/cm^2 can be obtained and that keyhole welding is now possible in steels up to 6mm thick. However, for pipeline applications, a high speed root pass technique is required and a review of the current state of diode laser technology concluded that the power density available from diode lasers would not meet the necessary productivity requirements.

The fibre laser is similar in concept to the end-pumped YAG laser, but the laser rod takes the form of a long optical fibre in which the core is doped with a laser medium – usually ytterbium (Yb) for oscillators or erbium (Er) for amplifiers. Pump light from laser diodes is introduced into one end of, or through the side of, the fibre cladding and via multiple internal reflections is progressively absorbed by the lasing element in the fibre core. The pump face of the fibre has a high reflectivity coating and the output end a suitably lower reflectivity coating, or Bragg gratings are etched on the fibre to form the resonator. Since the fibre core size is typically <10μm, and the length is many metres, the fibre laser produces excellent beam quality.

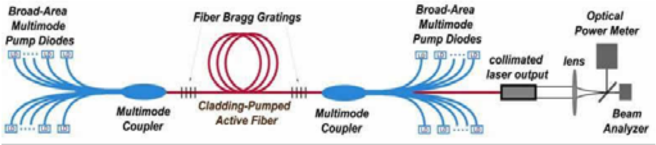

Figure 10. Basic configuration of a diode-pumped fibre laser.

The majority of commercial fibre lasers are of low power and used for micro-applications but in the last 12 months 4kW and 6kW units have been produced and an 8kW unit is currently being manufactured. Electrical to optical efficiency of these lasers can be over 20% so they do not require as much input power or as much cooling as Nd:YAG lasers. The high power fibre lasers have therefore been identified as the most promising technology for pipeline applications. The high beam quality means that performance will exceed that of the Nd:YAG lasers used in the YAGPIPE project and the small size and high efficiency means they are transportable. However this is a new technology and there are currently no 4-6kW fibre lasers within research organisations. It is thought however that this technology will be developed for pipeline applications within the next few years.

Developments in Forge Welding Processes

Flash-Butt Welding

Many miles of large diameter pipelines have been installed onshore in Russia and Ukraine using flash-butt welding and the system is still marketed [Figure 11]. McDermott licensed the process from the E.O. Paton Welding Institute and invested a significant amount of time and capital in developing it for laybarge operation with over 1500 full scale test welds being made. Following trials by McDermott, the process was also accepted for inclusion in API standard 1104. However, a pipeline was never installed by McDermott. Two reasons for this are the improvements in conventional welding systems and problems in achieving satisfactory mechanical properties with the available materials. Trials for Statoil on 36” pipe required a heating, holding and quenching cycle totalling 6 ½ minutes. Tensile and hardness values were acceptable but scatter and the occasional low fusion line Charpy impact value were of concern.

Figure 11. Flash-butt welding operation.

Induction Welding and Electric Resistance Welding

Both of these processes are similar in operation and both are used for seam welding pipes. In electric resistance welding, current is applied by direct contact and in high frequency induction welding a non-contacting induction coil is used. The HFI process is now acknowledged to produce high quality weld seams in linepipe. In seam welding, the pipe edges are gradually brought together within the electrical field but this is not possible in girth welding where the whole joint surface must be in contact. Due to the ‘skin effect’ obtaining uniform heating can be a problem.

US patent 441860 refers to an internal clamping method that can be used with an induction system to align the pipes and apply an axial force to pull the pipes together and create a forged weld. Mannesmann Anlagenbau has published a brochure outlining their proposed J-lay system and induction welding is proposed. They state that successful tests were completed on pipes up to 30” diameter and 40 mm wall thickness and they use the term ‘press butt welding’ to describe the process.

Spinduction Weld Inc of Edmonton Canada has recently been formed to develop a novel method of induction welding. The equipment development is being handled by Noetic Engineering (private communication: W. D. Roggensack, Noetic Engineering). The equipment used for small-diameter pipe is shown in Figure 12.

The Spinduction^{TM} welding process incorporates a combination of controlled thermal and mechanical processes to produce an autogenous weld between plain ended pipes. Pipe ends are positioned about 25mm apart. To avoid the problems of uniform heating caused by the skin effect, an induction heating system with a retractable coil is positioned between the pipe ends. The main phases, of the process are described as preheat, bonding, and quenching. The preheat phase is performed with the heating coil between the stationary pipe ends; during this phase, only the induction heating equipment is active.

Figure 12. Spinduction induction welding equipment.

Immediately following pre-heat, the induction heating coil is retracted and mechanical processes are initiated. First, the pipe ends are rapidly brought into contact. Rotation is started just before contact to ensure relative motion of pipe ends in the tangential direction at initial contact. Axial displacement of the pipe ends stops shortly after initial contact with control being based on position, not load. Rotation continues, with torque being applied as necessary, until the prescribed tangential displacement is achieved and rotation stops. Relative motion of the pipe ends that is imposed by rotation during the bonding phase is believed to accelerate diffusion between the mating parts, resulting in the desired autogenous weld. The weld cools in a controlled manner depending upon the initial preheat cycle. Additional quenching is possible but has not been found necessary. The process creates a narrow bond line and the degree of material upset can be controlled as shown in Figure 13.

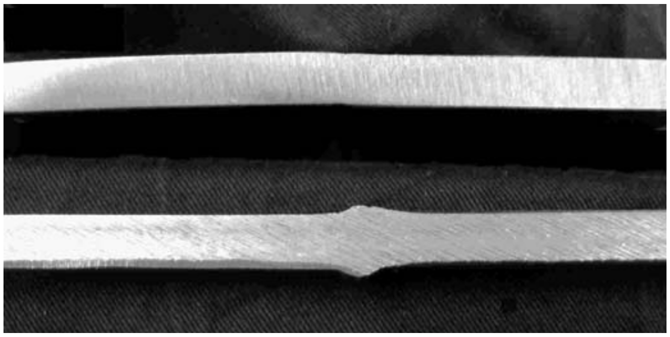

Figure 13. Control of weld flash in spinduction welding.

To date, work has been focused on downhole tubulars but welding of pipeline materials is planned in the near future.

Homopolar Pulse Welding

Homopolar pulse welding is a resistance process operating on the same principle as electric resistance and induction welding. In this case however, a homopolar generator is used to deliver a single very high current DC pulse and the weld operation takes only 2-3 seconds. Due to the short welding cycle, a narrow heat affected zone is formed. It is claimed that required mechanical properties can be obtained without post weld heat treatment.

Until recently, work was ongoing at the University of Texas at Austin. Parker Kinetic Designs specialises in the design and manufacture of homopolar systems for a range of industrial applications and they hoped to market homopolar pulse welding for pipelines. Most work had been completed on 3” steel pipe but some 12” diameter pipe welds had been made. Theoretically, the process can be scaled up to cover any size pipe with the required power being proportional to the cross-sectional area of the pipe. However, the research programme at the University of Texas was suspended early as it became clear that a very high capital investment would be required to make the process commercial.

Magnetically Impelled Arc Butt Welding

Developed for the joining of thin-wall steel tubing, MIAB welding is a high-temperature forge-welding process, which, in general, exhibits weld characteristics similar to the other hot forge techniques. The essential difference is in the way in which heat is generated prior to the application of the forging force. With the MIAB welding process, the square-edged pipe faces to be joined are separated by a small gap and a welding arc is established across the gap. A static, radial magnetic field is superimposed in the gap which causes the arc to move around the pipe ends as a result of the interaction of the arc current and the magnetic field. The speed of the arc is very high (150 m/s or greater) and results in uniform heating of both pipe faces. After sufficient heating time, the pipes are rapidly forged together to produce a solid phase bond with a characteristic flash or upset. A typical weld joint is shown in Figure 14.

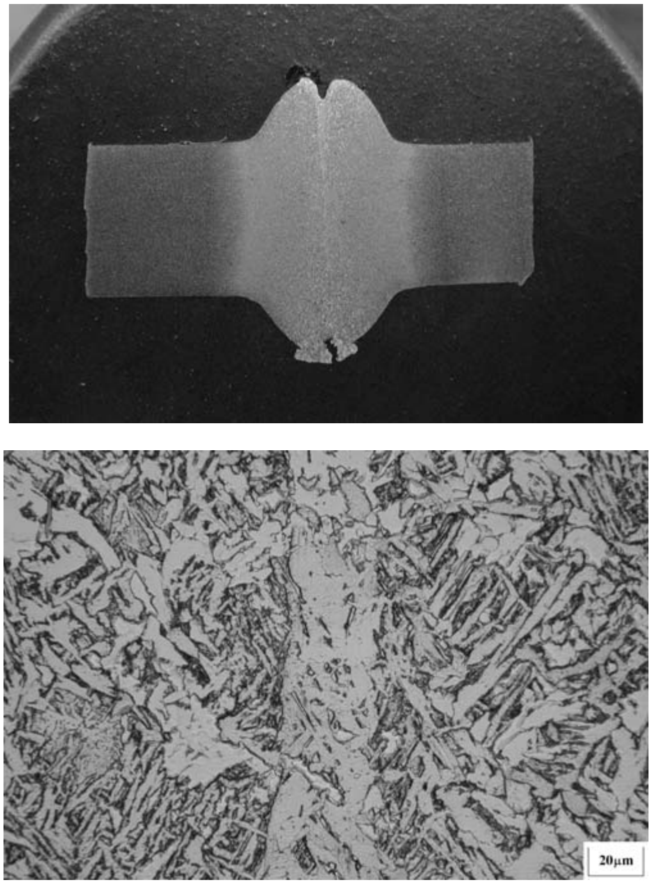

Figure 14. Typical weld profile and bond line in MIAB welding.

The process has been exploited mainly in the European automobile industry to weld a range of carbon and low-alloy steel components such as car and truck axles, drive shafts, shock absorbers and gas-filled struts. All of the commercially-available machines are stationary, floor- or bench-mounted units into which the parts to be joined are fed. A low-noise portable system has also been developed by NKK Corporation of Japan for welding of low pressure gas distribution pipelines in densely populated urban areas where excavation and construction can only be carried out at night and the excavations reinstated before dawn. The system was not designed for high production applications. An average of 60 metres of pipe per day was welded.

In order to determine the feasibility of the MIAB welding process for cross-country construction of small-diameter gas transmission pipelines, The Welding Institute was contracted to work with TransCanada PipeLines. A prototype system was designed and built by TWI and delivered to TransCanada where it was commissioned in 1992. Two welding head assemblies were produced. The first head is designed for NPS 3, 4 and 6 with a maximum forge force of 300 kN. The second head has jaw insert and magnet assemblies for NPS 6, 8, 10, and 12 pipe and a maximum forge force of 600 KN [Figure 15]. The process was proved suitable for small diameter thin wall pipes but the development of the MIAB system by TransCanada has currently been suspended.

Figure 15. MIAB NPS 12 welding head.

A limitation of the current process is the relatively thin wall thickness that can be welded because the rotating welding arc tends to move around the pipe diameter and does not heat the full wall thickness. However, this has not been seen as a major limitation by MIAB Technology Pty Limited, Victoria, Australia (private communication: L. Fletcher, MIAB Technology Pty Limited). They have recently been successful in winning a Commonwealth Government Start Grant that will allow them to demonstrate that they can produce MIAB welds which meet the performance requirements of the Australian Standard for pipeline welding AS2885.2. It is claimed that they can reduce construction costs by 15% in the short term and by 25% in the long term. The initial aim is to weld pipe up to DN200 and in wall thicknesses up to 6.3mm. In the longer term they plan to weld up to DN450 Class 900 X70 pipe or higher grade. The welding cycle time is claimed to be 1 minute, so in the right terrain they will be able to weld several or more kilometres per shift.

Summary

1) For many pipeline applications, mechanised GMAW is still considered the most suitable process. The use of dual-torch welding bugs has reduced construction costs and further reductions are predicted from the use of dual-tandem GMAW and novel root pass welding processes. The CAPS dual tandem welding system recently developed at Cranfield University has been use to complete girth welds in 30% of the time required for single wire GMAW, and has completed a successful field trial in arctic conditions.
2) Historically, most interest has been taken in the one-shot welding systems and one of the main reasons given is increased welding productivity. However, although the one-shot welding systems offer a total welding time much faster than the total welding time for GMAW systems, they must be completed in one welding station and the critical path operations can be much longer due to the slower setup and the need for post-weld operations such as flash removal. Also it has often been difficult to scale-up these processes to large diameter pipes. However, the power-beam processes do not suffer from the same problems, since multi-pass and multi-head welding is possible with laser and electron beam welding. These processes may also be used to partially complete a weld and an alternative process used for fill passes. Therefore, the power-beam processes are currently being more actively developed than the one-shot processes.
3) CO_2 lasers or Nd:YAG lasers can be used for pipeline construction, but the ability to use fibre-optic beam delivery

systems makes Nd:YAG particularly attractive. The YAGPIE project has demonstrated the potential production benefits of hybrid Nd:YAG laser – GMAW welding but the poor electrical efficiency of Nd:YAG lasers makes them unsuitable for use on a pipeline right-of-way.

4) High power fibre lasers are a new laser technology and their high beam quality and high efficiency overcomes the problems of Nd:YAG lasers and they should be suitable for pipeline applications.
5) Despite the lack of real success to date, development of one-shot welding continues with induction welding and MIAB welding currently being developed for pipeline girth welding applications.

Acknowldegements

Several organisations have provided data and images for this paper. The contribution of research students at Cranfield University is acknowledged, and in particular we would like to thank Mark Hudson for providing the cooling rate data in Figures 6 and 7 prior to publication.

References

Energy Information Administration (EIA), International Energy Outlook 2003 –Natural Gas. DOE-EIA0484(2003), May 2003, US Department of Energy, Washington, DC, USA

Oil & Gas Journal, pp 62 – 65, Feb 3, 2003, Vol 101, No 5

Oil & Gas Journal, pp 52 – 56, Sep 16, 2002, Vol 100, No 38

Hammond, J., Blackman, S. and Hudson, M. (2002), "Challenges of girth welding X100 linepipe for gas pipelines", In: Pipe Dreamer's Conference, Application and Evaluation of High-Grade Linepipes in Hostile Environments, Pacifico Yokohama, Japan, 7-8 November, 2002.

Hudson, M., Blackman, S., Hammond, J. and Dorling, D. (2002), "Girth welding of X100 pipeline steels", In: International Pipeline Conference IPC 02, Calgary, Alberta, Canada, 29 Sept - 3 Oct, 2002.

True, W.R.,"TCPL installation proves commercial use of X-100 pipe", Oil and Gas Journal, Feb 3 2003, Vol 101, No 5

Kuchuk-Yatsenko, S. I. and Krivenko, V. G. (1990), "Experience of flash-butt welding application in pipeline construction in the USSR", In: Pipeline Technology Conference. Proceedings, Oostende, Belgium, 15-18 Oct.1990. Ed: R.Denys. Publ: B-2018 Antwerpen and B-9000 Ghent, Belgium; Koninklijke Vlaamse Ingenieursvereniging (K.VIV) and Rijksuniversiteit te Ghent (RUG); 1990. ISBN 90-5204-010-9. Vol.A. pp.5.7-5.9..

Blackman, S. A. and Dorling, D. V. (2000), "Advanced welding processes for transmission pipelines", In: Pipeline Technology. Proceedings, 3rd International Conference, Brugge, Belgium, 21-24 May 2000. Ed: R.Denys. Publ: 1000 AE Amsterdam, The Netherlands; Elsevier Science BV; 2000. ISBN 0-444-50271-8. Vol.2. pp.371-387.

Blackman, S. (2001), "Developments forecast to reduce pipeline construction costs", Welding and Metal Fabrication, vol.69, no.8. Sept.2001. pp.7-10.

Booth, G. S. (2001), "Laser welding of land pipelines", In: New Developments in Onshore Pipeline Technology. Proceedings, International Conference, Loughborough, UK, 5-6 Dec.2001. Chairmen: R.Allen, S.Thomas. Publ: London, SW1X 8PS, UK; Pipeline Industries Guild; 2001. Paper 10.

Blackman, S. and Rosier, P. (1992), "Pipeline construction in the North Sea - meeting the challenge", In: Pipeline Reliability. Proceedings, International Conference, Calgary, Canada, 2-5 June 1992. Ed: R.W.Revie, K.C.Wang. Publ: Houston, TX 77252-2608, USA; Gulf Publishing Co.; 1992. ISBN 0-88415-077-1. Vol.2. Paper V-3.

Blackman, S. A. and Dorling, D. V. (1999), "Mechanised GMAW [MIG/MAG welding] for transmission pipelines", In: Pipeline Welding and Technology. Proceedings, ICAWT '99 International Conference on Advances in Welding Technology, Galveston, TX, 26-28 Oct.1999. Publ: Columbus, OH 43221-3585, USA; Edison Welding Institute; 1999. Session 5. Paper 1.

Blackman, S. A. and Dorling, D. V. (1999), "Capabilities and limitations of mechanised GMAW [MIG/MAG welding] systems for transmission pipelines", In: Weld Metal Hydrogen Cracking in Pipeline Girth Welds. Proceedings, 1st International Conference, Wollongong, 1-2 Mar.1999. Ed: L.Fletcher. Publ: Silverwater, NSW 2128, Australia; Welding Technology Institute of Australia (WTIA); 1999. [Paper 17.]

Norrish, J. and Henderson, I. (1999), "Productivity and costs of alternative pipeline girth welding processes", In: Weld Metal Hydrogen Cracking in Pipeline Girth Welds. Proceedings, 1st International Conference, Wollongong, 1-2 Mar.1999. Ed: L.Fletcher. Publ: Silverwater, NSW 2128, Australia; Welding Technology Institute of Australia (WTIA); 1999. [Paper 20.]

Dye, S. A. (1970), "New Automatic Machine for Pipe Welding", Metal Construction and British Welding Journal,March 1970,2,3,111-114

Hansen, E. and Poirer, N. (1995), "Offshore welding technology applied to a major onshore pipeline construction: Mahgreb to Europe 48 inch gasline in Morocco", In: Pipeline Technology. Proceedings, 2nd International Conference, Ostend, Belgium, 11-14 Sept.1995. Ed: R.Denys. Publ: 1000 AE Amsterdam, The Netherlands; Elsevier Science BV; 1995. ISBN 0-444-82197-X. Vol.3. pp.119-137.

Gainand, Y., Mas, J. P., Jansen, J. P., Coiffier, J. C., Dupont, J. C. and Vauthier, C. (2000), "Laser orbital welding applied to offshore pipeline construction", In: Pipeline Technology. Proceedings, 3rd International Conference, Brugge, Belgium, 21-24 May 2000. Ed: R.Denys. Publ: 1000 AE Amsterdam, The Netherlands; Elsevier Science BV; 2000. ISBN 0-444-50271-8. Vol.2. pp.327-342.

Yapp, D., Denney, P., Eastman, J. and Johnson, M. (1999), "Nd:YAG laser welding of high strength pipeline steels", In: Pipeline Welding and Technology. Proceedings, ICAWT '99 International Conference on Advances in Welding Technology, Galveston, TX, 26-28 Oct.1999. Publ: Columbus, OH 43221-3585, USA; Edison Welding Institute; 1999. Session 5. Paper 5.

Haake, J. and Zediker, M. (2000), "Diode laser welding makes strides onto shop floors", Welding Design and Fabrication, vol.73, no.9. Sept.2000. pp.39-42

Brinkmann, U. (2000), "Laser diode welds deep into [stainless] steel", Laser Focus World, vol.36, no.1. Jan.2000. p.28

Tonshoff, H. K., Ostendorf, A. and Schafer, K. (1998), "Fibre laser - compact source for micro-welding", In: Laser Materials Processing. Proceedings, Conference, ICALEO '98, Orlando, Florida, 16-19 Nov.1998. Chairmen: E.Beyer, X.L.Chen, I.Miyamoto. Publ: Orlando, FL 32826, USA; Laser Institute of America; 1998. ISBN 0-912035-58-7. Vol.85. Part 2. Section E. pp.106-111.

Turner, D. L. (1986), "Flash-butt welding of large diameter oil and gas pipelines", In: Proceedings, Pipeline Engineering Symposium, 1986; New Orleans, Louisianna, USA, 23-27 Feb.1986. Ed: E.J.Seiders. Publ: New York NY 10017, USA; American Society of Mechanical Engineers; 1986. pp.15-20.

Carnes, R. W. and Haase, P. W. (1995), "Homopolar pipeline welding, an overview", In: Underwater Welding of Marine Structures. Proceedings, International Workshop, New Orleans, LA, 7-9 Dec.1994. Ed: S.Liu, D.L.Olson, C.Smith, J.S.Spencer. Publ: New York, NY 10048, USA; American Bureau of Shipping; 1995. ISBN 0-918062-77-2. pp.299-300.

Carnes, R. W., Hudson, R. S. and Nichols, S. P. (1997), "Advances in homopolar welding of API linepipe for deepwater applications", In: Joining and Welding for the Oil and Gas Industry, Proceedings, International Conference, London, 30-31 Oct.1997. Publ: London, W1N 8JX, UK; IBC UK Conferences Ltd; 1997. Paper 10.

Ichiyama, Y., Asahi, H., Hudson, R. S., Carnes, R. W. and Hebner, R. (2000), "Homopolar pulse welding of martensitic stainless steel linepipe", In: Pipeline Technology. Proceedings, 3rd International Conference, Brugge, Belgium, 21-24 May 2000. Ed: R.Denys. Publ: 1000 AE Amsterdam, The Netherlands; Elsevier Science BV; 2000. ISBN 0-444-50271-8. Vol.2. pp.359-369.

Dorling, D. V. and Rothwell, A. B. (1990), "Field welding processes for pipeline construction", In: Pipeline Technology Conference. Proceedings, Oostende, Belgium, 15-18 Oct.1990. Ed: R.Denys. Publ: B-2018 Antwerpen and B-9000 Ghent, Belgium; Koninklijke Vlaamse Ingenieursvereniging (K.VIV) and Rijksuniversiteit te Ghent (RUG); 1990. ISBN 90-5204-010-9. Vol.A. pp.2.1-2.11.

Rothwell, A. B. and Dorling, D. V. (1990), "Welding technology for Canadian pipelines", Canadian Welder and Fabricator, vol.81, no.7-8. July-Aug.1990. pp.71-78.

Hudson, M, PhD thesis, Cranfield University, 2003, to be published