# USE OF AUTOMATIC WELDING PROCESS IN PIPELINES FOR MEETING TIGHT SCHEDULES

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## Abstract

Pipelines are becoming increasingly suitable for transporting hydrocarbons and other fluidic materials over long distances. With the demand for such transportation increasing steadily, pipelines are being designed to transport larger volumes and at higher pressures using higher strength materials to optimise the capital expenditure. Also, the project schedules are being shrunk to meet the cash flow calculations as well as to meet urgent demands. When the projects are required to be completed in much shorter duration times, conventional pipeline welding processes and laying procedures need to be changed to high productivity processes and procedures without compromising on the quality and safety levels. With modern high strength steels, a good knowledge of their weldability together with the capabilities and limitations of the high productivity welding processes and the related quality assurance requirements is essential for meeting the project schedules. This paper seeks to bring out the salient features of such high productivity processes adopted for Indian projects in recent times.


## Introduction

The ever increasing worldwide demand for energy resources such as crude oil and natural gas has resulted in the need to construct long distance, high capacity transmission pipelines. Many new and major oil and gas exploration sites are in remote locations and require the product to be transported to processing facilities located elsewhere. Also, the finished products are to be transported over long distances for the purpose of distribution to different domestic, industrial and military locations. It has long been recognised that pipelines are the most economical means of transportation of large quantities of fluids such as oil, gas and associated products. In addition to the advantage of minimising the transportation-related losses, nowadays pipelines provide a certain amount of insurance against terrorist related incidents, thus making them attractive as a socio-economically sound and politically correct choice for many nations across the world.

In almost all cases the pipeline construction cost dominates the economics of oil and gas recovery. Pipeline construction costs are known to exceed $1M-1.5M per mile in the case of onshore lines and $3M-5M per mile in the case of offshore lines. In India the cost is generally estimated as 7-10 lakh (100,000) rupees per inch (diameter) per kilometre in the case of onshore and about 3-5 times this cost in the case of offshore pipelines. In addition to this huge capital cost, there are also costs associated with the need to satisfy demanding operating requirements by extending pipeline design methods for ensuring compliance to requisite levels of safety as perceived by the asset owners and regulatory bodies.

For reasons of economy, it is necessary to carry out the pipeline installation within the shortest possible time period. Therefore, it is advisable to ensure that the material and the product dimensions do not create any problem at any time during the construction and operation phases. For achieving satisfactory economic returns on the investment, operators are focusing attention on the use of increased material strength (pipe grade) that allows higher operating pressures and smaller pipe thicknesses, thus reducing the total steel tonnage, transportation costs and the volume of weld metal needed during pipe installation. While it is recognized that, in order to derive maximum benefit from a pipeline project it is essential to understand the various issues, such as the route selection, material selection, design, fabrication, field welding, inspection, pipe laying scheduling, safety procedures, operation, etc., attention also needs to be paid to minimising the total time required for pipe laying, of which the joint welding of individual pipe and pipe sections represents one of the major time consuming activities.

This paper aims to share some of the experience gained in pipeline construction in India.

## Factors Affecting Productivity

Materials

A number of specification modifications have been made in the past, by various pipeline specifiers to continuously improve strength, weldability, resistance to sour gases and fracture resistance. Almost all of them are aimed at improving the economy of construction or at improving the levels of quality and reliability, recognising the necessity to minimise rework, which greatly affects productivity.

It was generally accepted that a decrease in the carbon levels of steels would greatly contribute to an increase in the pipeline steels weldability and toughness, both of which would help in decreasing the rework incidences during the construction as well as during operation phases. Lowering the carbon necessitated the use of some other mechanism for increasing the steels' strength levels. This was achieved by the introduction and use of controlled rolling processes and subsequently by the extensive use of micro-alloying elements in conjunction with the controlled rolling. Of course, the same effect was also achieved with quenching and tempering. The range of compositional types and steel processing routes for pipeline steels continues to expand with the aims of improving strength, toughness and weldability.

Increased demands for higher strengths, greater wall thicknesses, tougher pipes with excellent weldability under severe field welding conditions, etc. have further widened the range of available steel types, such as ultra-low carbon, controlled rolled, bainitic steels produced through the on-line accelerated cooling route. This combination of alloy type and process route is covered extensively in this paper. Today we have a number of steels meeting the API X70 and X80 requirements with Carbon less than 0.1%, and strengthened with additions of alloying elements such as Mn, Ni, B, Ti, V, Nb, etc.

Steel making and pipe manufacturing developments during the 1970s and 1980s resulted in the progressive evolution of API 5L Grade X65 to X70 and X80. In India, due to reasons of limitations of widespread capability for pipe production and field laying expertise, the use was generally limited up to X70, though a few projects for non-sour service are now executed with X80. In other parts of the world, viz. North America, Europe and China, Grade X80 pipelines have gained general acceptance. The economic benefits of further increases in strength have led to a focused attention on the next step increase to Grade X100 and even X120. A few of the major operators have recently announced joint ventures to build a major pipeline using Grade X100 pipe.

Whenever pipelines are to be used for sour service, they are required to possess adequate resistance to hydrogen sulphide. Since more and more wells in offshore fields are tending to turn sour at the later stages of their productive life, due to the action of sulphate reducing bacteria, most extraction pipelines may have to meet sour service requirements.

A sour service pipeline is required to possess excellent resistance to hydrogen induced cracking (HIC) and sulphide stress corrosion cracking (SSCC). To a large extent these requirements can be achieved by controlling the hardness of the material and by modifying the inclusion content and its morphology. Hardness control without affecting the strength is achieved by controlling the elements that contribute to the hardenability with simultaneous additions of microalloying elements such as Nb, Ti, B, etc.

The principal inclusion that contributes to HIC susceptibility is manganese sulphide, and hence the steels are required to have Manganese and Sulphur restricted to 1.4% and 0.003% max., respectively, in any steels designed for HIC resistance. For ensuring resistance to SSCC, the hardness and the strength of the steel are to be controlled. The generally accepted norm is to limit the specified minimum strength of the steel to 60,000 psi without post weld heat treatment (PWHT) and to 70,000 psi when PWHT is employed. In all such services, both the steel composition and the welding procedures are required to be designed suitably to meet the specification requirements.

Whenever higher productivities are aimed at, it should be recognised that the welding procedure utilises high heat inputs with associated PWHT (that again consumes time, thus decreasing the productivity) or uses high speeds of welding with minimum weld metal with the associated higher rates of cooling. In the case of pipeline welding, the possibility of post weld heat treatment should be ruled out, as it is almost impractical to carry out PWHT in any pipe laying operation. Therefore, in the case of the pipeline welding, the choice automatically falls on the high speed processes which utilise narrow gap edge preparations that decrease the amount of weld metal to be deposited and thus decrease the arcing time, with the associated low heat inputs and faster cooling rates. In order to accommodate the faster cooling rates, the steel used for the pipe should be capable of developing low hardness in the heat affected zones and hence the earlier discussed low carbon steels with micro alloying additions naturally become the preferred choice.

## Welding of Linepipes and Pipe Lines

With the ever shrinking schedules of pipeline projects, it is imperative that the linepipe manufacturers adopt high productivity shop floor procedures and welding/quality assurance practices. Most of the linepipe manufacturing units use Gas Metal Arc Welding (GMAW) and Submerged Arc Welding (SAW) processes for the root welding and filler passes, respectively, for achieving high productivity in order to match the agreed and shrinking supply schedules. Both SAW and GMAW, used for the bulk of the shop welding joints, involve high heat inputs (slower cooling rates) and hence concerns related to the hardness control, etc. that are usually associated with higher strength steel grades, are generally not an issue. But, when Thermo Mechanically Controlled Process (TMCP) plates are welded with such processes, retention of properties in the Heat Affected Zones (HAZ) of the weldments needs to be specifically ensured through process control.

However, the same combination of welding processes used for production cannot be used for pipe laying. In the earlier days, most of the welding was carried out by the Shielded Metal Arc Welding Process (SMAW) and ingenious ways were adopted to increase the productivity in the field. The most important was to adopt a gang concept in which separate groups of welders with the specific skill sets required for individual passes were used for the root pass welding, hot pass welding and filler pass welding. In this method the speed with which the root pass was completed would decide the pipe laying speed. To achieve high root pass welding speeds with proper root penetration and fusion, normally cellulosic electrodes were utilised using the stringer bead technique in the vertical down position. As the root welders move on to the next pipe joint, the hot pass gang takes over without losing much time in order to obtain a crack free weld metal, followed by the gang of filler pass welders who complete the filler and later the cap passes, in order to ensure freedom from hydrogen cracking. The presence of large quantities of hydrogen in the weld metal originating from the cellulosic electrode makes it necessary to produce steels with very low carbon equivalent to prevent problems due to diffusible hydrogen in the weld and HAZ. High productivity can be achieved only if defect free root and filler passes are ensured and hence the entire emphasis used to be on the root pass with welders trained to achieve specific quality levels. For the purpose of rendering the root pass highly ductile and resistant to cracking under the solidification and restraint stresses in a thin solidifying root bead created by the stringer bead technique, it is advisable to use an under-matching weld metal for the root weld and hence almost always cellulosic electrodes of classification E6010 need be used for the root pass of pipes of all strengths.

This technique is very easily employable for steel pipes up to API X65 grade. But, such an approach with cellulosic electrodes tends to pose problems when the strength levels increase to X70 grade and beyond, since the presence of copious amounts of hydrogen necessitates adoption of fairly high preheats, of the order of 150 – 175 $^{o}$C, which is rather difficult to implement under field conditions due to the increase in hardship faced by the welders, especially under hot ambient temperature conditions. Under these conditions, it becomes necessary to use a low hydrogen electrode, which is usually suitable only for vertical up welding with a corresponding lower productivity. Though some manufacturers have formulated low hydrogen vertical down SMAW electrodes, they have not been widely accepted in the pipe laying industry due to various reasons.

The popularity of the SMAW process for the pipe welding applications across the world was due to the simplicity of its operation and the continuous availability of trained welders to cater to the gang concept. The various attributes of the SMAW process that contributed to its popularity include:

1. The constant current welding equipment with the single weld control is simple to operate and inexpensive to purchase. The equipment is typically durable and simple to repair.
2. The SMAW electrodes provide a fast freeze weld slag that can assist in the control of the weld.
3. The SMAW electrodes provide low current density resulting in fast freeze weld solidification; this is an important benefit for all-position welding.

4. In contrast to the alternative welding processes, the SMAW weld process requires minimum "welding process expertise."
5. Electrode manufacturers can formulate the SMAW electrode flux to meet specific chemistry and mechanical property requirements.
6. The low weld deposition rates achieved with SMAW can be actually beneficial for "manual" pipe welding. The low weld deposition rate requires the welder to travel at a low manageable weld travel rate. The slower the welder travels the more time is available for the welder to manipulate the weld pool, to properly control the fast freezing and shallow penetration of the weld metal into the pipe bevel.

If the benefits of available welding process technologies are evaluated objectively, ignoring the occasional biased sales advice, then one can arrive at the following conclusions for field pipeline welding applications:

Many variables can affect the field pipe root dimensions. If the skilled labour force is available, the vertical down SMAW process has always been, and still today is, considered the practical choice for many root pass welds performed both in the field and in the spool fabrication pipe shops. The SMAW process used for the pipe root is still the best choice if the pipe root gap or pipe dimensions vary. For thin wall pipe, spool fabrication or for applications where the pipe diameter is less than 15 cm, it is often more logical to use the SMAW process if the skilled labour is available, or even the Gas Tungsten Arc Welding (GTAW) process, rather than to utilise the pulsed GTAW or Surface Tension Transfer (STT) processes for lower strength grades of steel.

As the cellulosic SMAW root pass is typically not thick, it can also be utilised to support the use of the higher energy, high productivity flux-cored welding process, which needs a support at the bottom to neutralise its excessive penetration. By the same logic, SMAW welding can be used to provide one or two passes at the root to support the SAW process in thick wall plate welding applications.

But, for the higher strength steels, it is always advisable to use a process that minimises or eliminates the presence of hydrogen in the weld region. Since low hydrogen electrodes are associated with low productivity due to the need to use interpass grinding for slag removal and the necessity to use vertical up welding techniques, they are not preferred for high productivity pipe laying operations. Fortunately, today the weld decision-makers can select from a wide variety of high productivity welding processes, equipment and welding consumables for producing pipe welds.

Mechanised Pipe Welding

Over the last 50 years, mechanised pipe welding has been developed and improved so that welds can be made with consistent high quality and high productivity, and systems are available from several pipeline equipment contractors. A typical layout of the automatic field welding unit is shown in Figure 1, below. The sequence of developments in the automatic welding sector is also summarised below.

In the 1960s, CRC Crose (now CRC Evans) developed mechanised gas metal arc welding (GMAW), initially with a 40 degree-included angle weld preparation and stringer beads, and subsequently with a narrow groove weld preparation with torch weaving to achieve side-wall penetration. The welding head (bug) travelled on a simple track clamped on to the pipe, and the welds were made with two bugs on either side of the pipe, travelling downwards from the 12 o'clock position to the 6 o'clock position. During the past 50 years, mechanised pipe welding has been further developed and improved so that welds can be made with consistent high quality and high productivity, and these systems are available from several pipeline equipment manufacturers.

Figure 1. Typical field welding station for automatic welding.

**Root Pass Welding Automation Development**

- 1970s – Internal welding machine (IWM) with three, four or five welding torches operating simultaneously was successfully developed.
- 1980s – External root welding with internal copper backing ring was introduced.
- 1990s – Root welding without backing, using controlled dip transfer GMAW was introduced.

In the case of small diameter pipe joints and tie-ins (closing welds) in larger diameter lines, the use of internal welding systems is impossible and hence only the single-sided, external approach must be adopted. The introduction of modern power sources with control of metal transfer has made the external welding without copper backing possible. For example, the Lincoln surface tension transfer process (STT) can be used with a root gap to achieve high-quality root runs. The STT process operates by detecting both the short circuit and the incipient rupture of the liquid metal ridge at the short circuit, and adjusting the welding current so that stable transfer is achieved at low-heat input and with little or no spatter. Several other controlled-deposition processes have been shown to have capability for one-sided root welding, including Fronius' CMT (Cold Metal Transfer) and Kemppi's FastROOT.

**Filler Pass Automation Developments**

- 1960s -- Introduction of Narrow Groove welding and a single torch bug
- 1990s -- Introduction of Dual-Torch welding – two single wire torches on one welding bug
- 2000 -- Introduction of Tandem welding – two wires in one welding torch
- 2004 -- Introduction of Dual-Torch Tandem welding (CAPS system)
- 2007 -- Introduction of Automated Control of Torch Position Computerised Data Acquisition.

These developments use solid-wire GMAW, usually with $CO_2$ or Argon/$CO_2$ gas mixtures. Flux-cored wires have also been used with mechanised welding bugs, welding upwards, and using an API 60 degree bevel weld preparation, rather than the narrow-groove alternative. The efficiency of filler and cap processes determines the number of fill stations required. This takes on increasing significance as the pipe wall thickness and diameter increase.

The original CRC-Crose GMAW mechanised welding systems utilised a single torch and wire feed. Serimer Dasa (now Serimax) introduced a welding system with two welding torches on one welding bug (dual-torch system), which has been used extensively onshore and offshore. The introduction of the Tandem GMAW process by Cranfield Institute of Technology provided further possibilities for increasing pipe welding productivity. Tandem GMAW, Figure 2, uses a single torch with two contact tips to feed two wires into a single weld pool, enabling high welding speeds of up to 1m (40 inches) per minute. Two tandem torches can also be used on one welding bug, to further reduce the welding time, Figure 3.

Figure 2. Tandem welding torch.

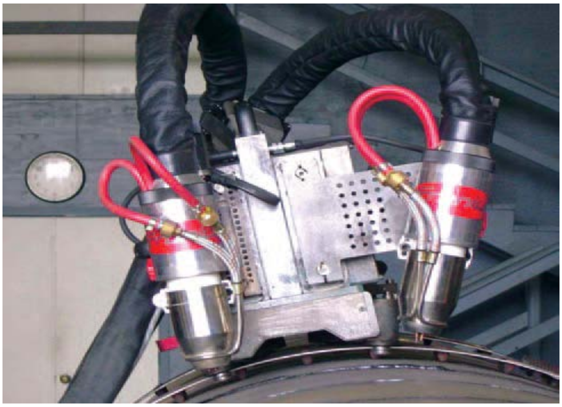

Figure 3. Tandem welding head.

A major feature of the process developments mentioned above is that they all evolved from existing technology. Welds made by the four different process variants (single-wire, dual-torch, tandem and dual-tandem) all have similar macrostructures, and hence conventional radiography and automated ultrasonic testing can be used for defect detection.

Some of the choices available today for high productivity in welding operations include:

1. Traditional MIG equipment using short circuit, globular or low current spray transfer for vertical down root and hot pass welds.
2. Surface Tension Transfer Process power sources, from Lincoln Electric (similar to a low pulsed setting) which, in contrast to short circuit, provides an improvement in the weld fluidity attained that is effective for welding the root passes with very good results.
3. Traditional short circuit pulsed or STT with metal-cored wires with better pulsing controls on metal transfer.
4. Pulsed MIG Process with MIG solid wires used for vertical up as well as vertical down welds.
5. A pulsed unit using AC/constant current, using MIG solid or metal cored wires.
6. Traditional MIG spray transfer systems with regular MIG solid or metal-cored wires for rotated pipe fill passes.
7. All position, gas shielded flux-cored wires for fill passes, typically made in the overhead and vertical up positions.
8. All position gas shielded flux cored wires designed for vertical down welds.
9. Gas Tungsten Arc Welding (GTAW) or the Plasma Arc Welding (PAW) systems mounted on orbital welding units.
10. Twin MIG welding head for metal cored wires, Figure 2.
11. The Miller RMD a short circuit mode which uses less current for a given wire feed rate.
12. The Fronius CMT process, another modified short circuit mode GMAW unit.

When appropriate welding process expertise is available, all the above mentioned welding processes and consumables can be adapted to pipe welding operation for increasing productivity with minimized training period, as these are relatively simple to operate. The main challenge for many weld decision makers is to see through the sales biased information being disseminated, on some welding processes and products, that can often adversely influence a decision making process.

**Automatic Gas Metal Arc Welding**

The development of fully automatic welding which takes away the dependence on manual welders was always a dream of the pipeline welding industry, which was realised in the late 80s. Several systems reached maturity with the introduction of advanced controls for the chaises movement, seam tracking, wire feed rate control, pulsed current power sources, electrical controls and synergic process controls, etc., and a better understanding of the role of various inert and active gas mixtures for obtaining the desired mechanical properties and metal transfer characteristics.

Almost all of them are designed to work with a narrow gap edge preparation, mostly carried out at the job site just before the commencement of welding in order to provide clean, accurate and undamaged edges for welding. All systems use a relatively high current for the wire size used to ensure the high deposition rates (>2.5 kg/hr) that are required for rapid completion of the joint, as well as for ensuring adequate heat input to fuse the sidewalls. Figure 4 below shows a sketch of a typical edge preparation used for narrow gap welding.

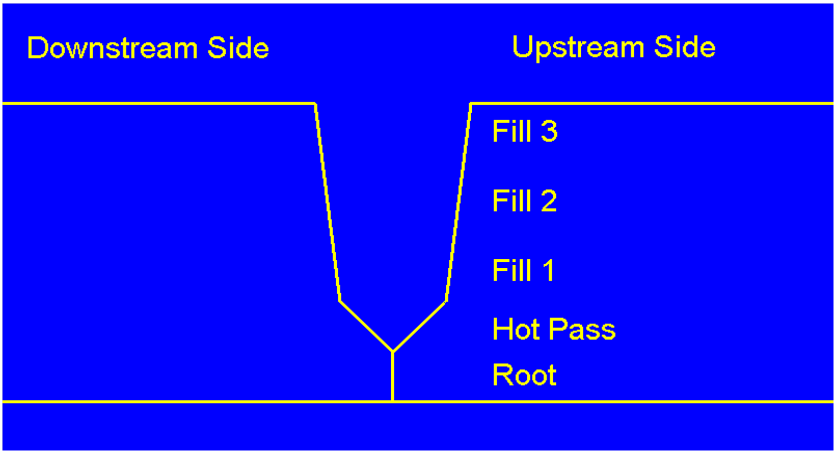


Figure 4. Typical edge preparation for automatic welding.

Automatic narrow gap GMAW is normally carried out in the vertical down direction and fusion is aided by weaving the welding head across the joint for filling and capping passes or by rotating the arc by using special twisted or twinned wires or by oscillation mechanisms. The following equipment manufacturers produced some of the successfully used systems in India:

1. CRC – Cross Automatic by CRC Automatic Welding, USA.
2. HC Price Automatic by HC Price Company, USA.
3. CRC Automatic Welding System by CRC, USA.
4. Saturn System by Serimer Dasa ETPM, France.
5. Saipem-Arcos-Passo-System by Saipem.
6. PWT Computerized Welding System by PWT spa, Italy.
7. Automatic Marine Pipeline welding System by McDermott, USA.

It is good practice to conduct systematic evaluations of the specific welding systems under practical field conditions to verify the claims made by the manufacturers instead of relying only on the technical brochures and track record data provided by the vendors, in order to avoid embarrassing surprises later during the actual execution. Usually, almost all the high productivity systems tried took a long time to get stabilized under field welding conditions. Once stabilized, these processes are capable of yielding high productivity, i.e. large volume of production with low repair rates.

Here, it is worth mentioning that, even though all these systems are classified as automatic or semi-automatic welding processes, they do require a certain degree of human intervention during execution for fine tuning the welding parameters or for correction of the position of the welding head as the welding progresses.

Higher productivity is achieved with all the semi-automatic, mechanised and fully automatic welding systems. The last two in the mentioned list gain extra productivity by being able to weld in the downhill direction within a narrow compound bevel weld edge preparation. Three potential benefits accrue from this set up. The narrow joint requires less weld metal to fill it, thus saving time and cost at a given deposition rate. Secondly, the joint holds the weld pool in place so well that high currents can be used without loss of control. Thirdly, the efficient heat sink effect cools the weld pool faster, allowing higher strengths to be achieved with less alloying elements in the weld metal.

Recent developments in metal cored tubular wires have thrown up new possibilities for the high productivity welding of high strength steel pipes. As the metal cored wires generally contain very small quantities of non-metallic arc stabilizers and other materials which assist the wetting action of the molten weld metal, lower spatter and defect levels can be attained. This also can lead to higher productivity than the solid wire GMAW processes that can be used under similar circumstances.

A Look at MIG and Flux Cored Weld Automation

With pipe weld automation, often the same issues that are found in the manual welding shops occur. One of the biggest challenges faced by any weld decision maker is to ensure that the new robots or automated welding equipment do not inherit the bad weld practices found in the manual weld shops.

The main reason for poor quality in automated welding or productivity performance is a “lack of welding process expertise”. To derive full benefit from the fully mechanised or semi automatic MIG or Flux-Cored Arc welding processes, the welding engineers need to possess the following:

1. A good understanding of the welding process fundamentals.
2. A thorough knowledge of the electrode wire welding parameter ranges, and the relationship between the various parameters and the weld equipment controls.
3. Awareness of the primary features, benefits and disadvantages of each welding process and the consumable used.
4. A good understanding that the primary method for weld cost control comes from the understanding of the relationship between wires feed and weld deposition.
5. A good understanding of the relationship between the welding current, wire diameter and the thickness of the part being welded.

It is well recognised that the majority of pipe weld defects that require weld rework and additional costly radiography, occur typically in the root and the first hot or the first filler passes, and also at the weld start-stop tie-ins. Most semi automatic MIG and Flux Cored Arc (FCA) weld defects are greatly influenced by the welding operators using inappropriate weld settings, poor weld practices and wrong wire stick-out in their welding techniques.

Weld automation allows control of both the weld speed and the weld weave, and the use of sophisticated welding power sources and automated equipment enable the welding parameters to be changed at different clock positions of the pipe joint. These are key elements for attaining consistent pipe weld quality. With welding automation, one can achieve a dramatic increase in the consistency and decrease in defect rate, both of which contribute to the weld productivity.

As operators start to use higher strength materials, it becomes even more necessary to use advanced high productivity mechanised welding processes that are capable of ensuring least alteration of the base material properties while at the same time obtaining an over-matching strength of the field weld metal capable of satisfying the strain based design (SBD) requirements. Adoption of the narrow gap edge preparation that goes with the automatic welding processes becomes an advantage as it helps decrease the weld metal volume and achieves high productivity and higher strength levels with minimum effect on the HAZ. Achievability of higher weld strengths than the base, by the automatic welding procedures makes the automatic high productivity processes an obvious choice when strain based design is resorted to.

There are a number of newer materials joining technologies that are being investigated to reduce the pipeline construction cost. These are Laser Pipeline Welding, use of high strength pipeline materials, and use of Advanced Automated Inspection. Tests have shown that the Hybrid Laser Arc Welding (HLAW) process, which combines the Laser Beam Welding (LBW) and GMAW processes, offers a number of benefits in terms of higher productivity, ability to produce welds with excellent material properties and in terms of increased tolerance of fit-up variations. For existing laser power levels, a viable scenario for implementation of lasers for pipeline welding applications is the use of HLAW for the root bead welding, followed by conventional Pulsed GMAW for completing the filler and cap passes.

The non-destructive testing procedures adopted for use with any high productivity welding procedure must also match the high speeds of joint completion aimed at. Traditionally, radiography was the preferred method. But, it must be remembered that any NDT procedure used must be capable of effectively detecting the types of defects anticipated in the particular welding process and the joint configuration employed. Therefore, an informed review must be carried out to choose an appropriate NDT technique which would possess the highest probability of detection of all the types of defects that are likely to occur in the field joints and would be capable of consistently and accurately detecting the size, the location and the orientation of the defects. This requirement becomes quite acute when modern steels of high strengths are used with minimum margins on thicknesses and Engineering Critical Analysis (ECA) based acceptance criteria are adopted.

Non destructive testing of the field welds can be done by X-ray radiography or by a suitably formulated automated ultrasonic testing procedure. Since the automatic/mechanised welding normally makes use of small bevel angles in a narrow gap configuration, the most probable defects occurring in field joints would be lack of side wall fusion, which is basically a planar defect with good ultrasound reflectivity. Also, when GMAW is employed, volumetric defects such as slag inclusions and porosity are likely to be absent. These planar defects are revealed more consistently by automated ultrasonic testing (AUT). With AUT the results can be studied on-line when the welding is in progress so that remedial action to tackle the defects can be taken instantaneously. The time taken for decision making for the clearance of the joint would be even less than the time taken for the joint completion using automatic welding. Therefore, it is considered essential that any high productivity welding procedure used for pipe laying should also incorporate inspection by AUT for effectiveness. However, the necessity for imparting extensive training on AUT to the existing quality assurance personnel and the need to carefully choose the AUT system and the AUT operator, must be recognised and a timely action for training taken for the success of the entire operation.

The time taken for completing the inspection of the entire girth weld of a large diameter pipe under field conditions would be typically in the range of 2 minutes. Since immediate feedback would be available, the welding crew can alter the welding parameters on line and that can eliminate the necessity for repairs later. Since there is no radiation hazard, all other construction activities can be performed in parallel and this also contributes to higher productivity. The NDT results would be available both as soft data and as hard print out and hence, post processing for future reference and use is easily facilitated.

For effective use as a substitution for the generally accepted radiography, an AUT system must be carefully chosen and evaluated prior to its deployment. For ensuring the reliability of the system, the AUT equipment should be mounted on a track that would fit on the pipe contour. It should incorporate both Pulse Echo and Time of Flight Diffraction (TOFD) or Phased Array (PA) techniques, probes for both of which should be mounted on the fully automated chaises in such a way that both would acquire the defect signals simultaneously over the entire circumference of the pipe joint and display the results on a single screen on line for every joint inspected separately. The system employed should also have advanced capability for post processing for accurate assessment of the defects and should have adequate data storage capacity along with wireless data transmitting facility from remote locations. Girth weld defect sizing results, as measured by mechanised ultrasonic testing Pulse/Echo, TOFD methods and PA ultrasonic technology utilising the zonal discrimination method with focussed and non-focussed search units, could be used in support of pipeline reliability assessments. All such advanced non-destructive testing together with the automatic welding techniques have contributed immensely to increasing productivity in pipe laying operations. One live example of the decision making process used in India and the resultant higher productivity achieved is given below in Annex A for information.

## Conclusions

Pipeline projects are increasingly used as an economic mode of fluid transportation over long distances. The necessity to complete the pipeline projects in short durations makes it imperative to use high productivity pipe laying procedures incorporating automatic welding procedures and automated ultrasonic testing procedures. A number of advanced welding systems have been developed and are available for use by pipeline operators, but it is necessary to train their technical staff on the fundamentals and relationships between the various welding parameters and the quality/productivity of the welds, for deriving the full benefits of the automatic welding processes. Such high productivity processes possess a number of additional advantages which will make them even more appropriate when higher strength materials and strain based design concepts are sought in future. The pipeline industry should take timely action for training their engineers and technicians so that high productivity and quality can be obtained to satisfy pipeline operators' expectations.

## Annex A - An Example of High Productivity Achieved to Meet Tight Schedules in India.

<u>Schedule of Pipe Laying:</u>

- Schedule for pipeline construction : 15 months
- Mobilization : 3.5 months
- Monsoon to be excluded : 3 months
- Hydro testing, dewatering, sectionalizing valves : 2 months
- No of days available for welding : 7 months (200 days)

<u>Estimated Production Rates of Different Welding Techniques</u>

(Inches of weld length per minute)

| | |
|---|---|
| SMAW (Celulosic V/D) | : 12 |
| SMAW (Low Hydrogen V/D) | : 7 |
| Pulsed GMAW (STT) | : 15 |
| Auto GMAW Outside Welding with Copper Back up | : 40 |
| Auto GMAW (with inside welding) | : 50 |

Alternative welding Procedures Evaluated for Productivity

Alternative I

| | |
|---|---|
| Joint Preparation | : API Bevel |
| Root | : SMAW (Cel. VD) |
| Fill & Cap | : Semi Automatic FCAW (Inner Shield) |
| NDT Examination | : X-RAY Supplemented by UT |

Alternative II

| | |
|---|---|
| Joint Preparation | : API Bevel |
| Root | : SMAW (LH VD) |
| Fill & Cap | : Semi Automatic FCAW (Inner Shield) |
| NDT Examination | : X-RAY Supplemented by UT |

Alternative III

| | |
|---|---|
| Joint Preparation | : API Bevel |
| Root | : Pulsed GMAW (STT Welding) |
| Fill & Cap | : Semi Automatic FCAW (Inner Shield) |
| NDT Examination | : X-RAY Supplemented by UT |

Alternative IV

| | |
|---|---|
| Joint Preparation | : $5^o$ Compound Bevel |
| Root | : Auto GMAW with Copper Back up |
| Fill & Cap | : Semi Automatic FCAW (Inner Shield) |
| NDT Examination | : X-RAY Supplemented by UT |

Alternative V

| | |
|---|---|
| Joint Preparation | : $5^o$ Compound Bevel |
| Root | : Auto GMAW (with inside welding) |
| Fill & Cap | : Auto GMAW |
| NDT Examination | : X-RAY Supplemented by UT |

Production Rates Achieved

Alternative I

| | |
|---|---|
| Root pass | : SMAW (Cell VD) |
| Fill & Cap Pass | : Semi Automatic FCAW Inner shield |
| Average welding production per day | : 54 Joints |
| Length of linepipe welded per day | : 0.65 km |
| Length of pipeline welded in 200 days | : 130 km |

| | |
|---|---|
| Alternative II | |
| Root Pass | : SMAW (LH VD) |
| Fill & Cap Pass | : Semi automatic FCAW (Inner Shield) |
| Average welding production per day | : 39 Joints |
| Length of linepipe welded per day | : 0.47 km |
| Length of pipeline welded in 200 days | : 93 km |

| | |
|---|---|
| Alternative III & IV | |
| Root Pass | : Pulsed GMAW (STT Welding) |
| Fill & Cap Pass | : Semi Automatic FCAW (Inner Shield) |
| Average welding production per day | : 61 Joints |
| Length of linepipe welded per day | : 0.73 km |
| Length of pipeline welded in 200 days | : 146 km |

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|---|---|
| Alternative V | |
| Automatic welding from inside and outside | |
| Average welding production per day | : 93 Joints |
| Length of linepipe welded per day | : 1.11 km |
| Length of pipeline welded in 200 days | : 223 km |