TEHNOLOGIČNO ZAVARIVANJE KORIJENOG PROLAZA

A COST EFFECTIVE ROOT PASS

James LAMOND [1], Kenneth Y. LEE [2]

Ključne riječi: otvor korijena zavara, korijeni prolaz, čvrstoća cijevi, brzina zavarivanja, troškovi ručno, polu-automatsko, automatsko, mehanička svojstva, difuzijski vodik, dodatni troškovi

Key words: root gap, root pass, pipe strength, welding travel speeds, costs, manual, semi-automatic, automatic, mechanical properties, diffusible hydrogen, outrun costs

Sažetak: Korijeni prolaz je možda najkritičniji prolaz na obodnim zavarima na cjevovodu. Bez obzira na to koji se postupak zavarivanja koristi za korijeni zavar, jasno je da postoje mnogi čimbenici koji su već razmatrani i objašnjeni.

Abstract: The root pass is perhaps the most critical pass on a cross-country pipeline girth welds. Whatever process is used for the root pass it is clear that there are many more influences than might have been previously thought of or discussed.

[1] Pipeline Welding Engineer, Lincoln Electric Europe
[2] Pipeline Welding Engineer, Lincoln Electric USA

A COST EFFECTIVE ROOT PASS

The root pass is perhaps the most critical pass on a cross-country pipeline girth welds for several reasons. First, it is generally the most difficult pass to make. It requires excellent skill to make a sound weld around the pipe joint, which may vary in gap width and offset. Second, the root pass speed determines the speed at which the pipeline may be constructed. Thus, any delay in the root pass slows down the project. Third, the back-bead of the root pass completes the critical inside surface of the pipe. Fourth, any root pass defects usually require a through thickness repair, which is the most costly and time-consuming type of repair.

MANUAL & SEMI-AUTOMATIC ROOT PASS WELDING

5P+ in the Sahara Desert

On a cross-country pipeline, the root pass is usually welded manually (using stick electrodes) or Semi-automatically (using wire) from the outside with the joint fit-up by an internal pipe clamp, which sets the joint gap and helps round out the pipe ends. An open root gap is commonly welded using several open arc-welding methods:

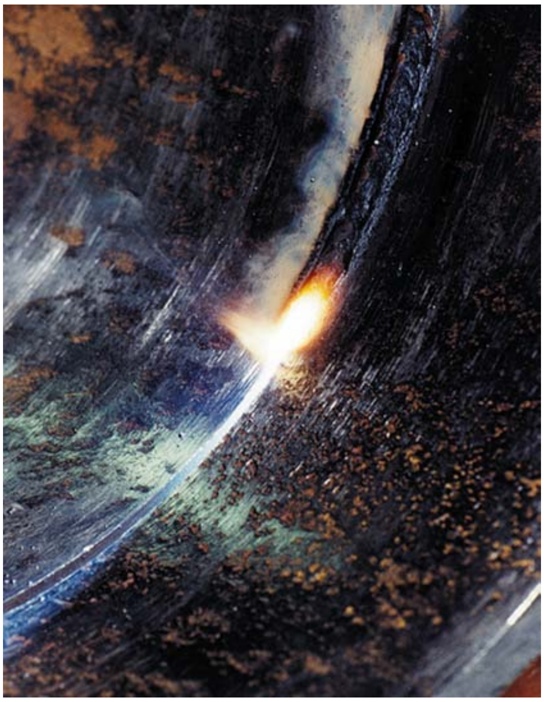
Manual EXX10 cellulose electrode, vertical-down progression. This is the most popular method and offers the fastest welding speeds. Cellulosic electrodes may also be used vertical-up with slower travel speeds to handle greater variations in joint fit-up.

Manual EXX16 or EXX18 basic low-hydrogen electrode, vertical-up progression. While travel speeds are slow, this is the only option for welding a manual low-hydrogen root pass.

Semi-automatic Surface Tension Transfer (STT®) current controlled short circuit gas metal arc welding (GMAW-S), vertical-down progression. STT®offers a low-hydrogen deposit at high welding speeds. (Table 1)

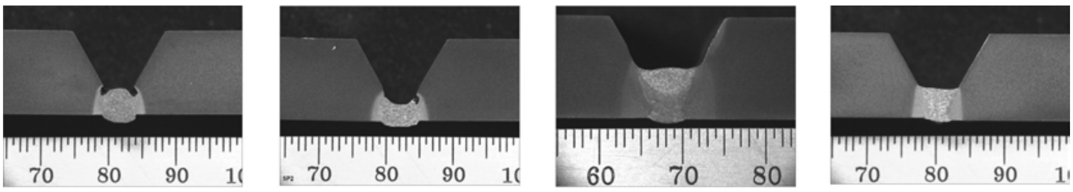
Open root joints are typically prepared with a 30-degree factory bevel and a root face of 1/16 inch (1.6mm) land, according to API 5L Specification for Line Pipe. Sample weld cross-sections of these root pass-welding processes on 12.7mm wall steel pipe are illustrated in Figure 1.

The speed of root pass determines how fast the next section of pipe can be attached. Thus, the root pass determines how fast the entire pipeline can be constructed. Consistent root pass speeds with minimal downtime is critical to keep pipeline construction on schedule.



STT® root pass welding (Inside Pipe).

STT® root pass welding (Outside)



Cellulosic | Cellulosic after grinding | Low - hydrogen Stick (2 pass) | STT® (GMAW - S)

Figure 1: Root Pass welds cross-sections

Root pass-welding speeds recorded from past pipeline welds are listed in Table 1. Actual root pass speeds will vary depending on many factors, and it should not be assumed that this would be the expected result for a particular application.

Table 1: Root Pass Welding Travel Speeds

	Welding Direction	Speed mm/s	
Manual		Single	Twin
Cellulosic	Down	4.5	
	Up	1.9	
Low Hydrogen	Up	1.2	
Semi Auto			
STT® Process	Down	4.5	
Automatic External Root			
STT® Process	Down	7	
Copper Shoe	Down	9	16
Internal Root	Down	21	(6 heads)

While cellulosic manual electrodes with vertical-down progression offer the highest travel speeds, it has two main drawbacks. It leaves deep undercut grooves on the edges of the weld face (commonly called wagon tracks). It is usually necessary to expose the wagon tracks so they can be consumed by the "hot" pass, this is done by removing the weld crown by grinding. Thus, extra time is required after the root pass is welded to remove part of the weld and then replace this with new weld metal. Also, cellulosic electrodes have relatively high diffusible hydrogen levels, making it crack sensitive on higher strength pipe grades.

Table 2 [3]

PR-164-9330, Table 10

Welding Process	Current (A)	Voltage (V)	Hydrogen Levels Mls/100gDM Average
Cellulosic	104	24.9	36.71
Basic (Undried)	111	21	9.56
Basic (Dried)	113	19	5.59
Solid + STT	220	16	1.34

Table 10 - H_2 Results for Root Welding Consumables

LINCOLN ELECTRIC

The low hydrogen manual root pass produces are flat weld face with less weld reinforcement than cellulosic on the inside of the pipe. It produces a thick crack-resistant root weld. Its drawbacks are it requires a very skilled welder and it results in slow welding travel speeds.

The STT® root pass offers fast travel speeds and a low-hydrogen weld deposit. It also produces a flat weld face with less weld reinforcement than cellulosic. Its drawbacks are it requires a dedicated power source, wire-feeding equipment, and utilises gas-shielding, which requires wind protection.

AUTOMATIC ROOT PASS WELDING

Automatic welding is increasingly being used for cross-country pipelines, especially on larger higher strength pipelines. Automatic welding precisely controls the welding parameters, which helps to obtain the high levels of strength and toughness required on many of the new pipe steels. Three popular automatic root pass methods are:

- External root pass on open gap, using STT®(current controlled GMAW-S)
- External root pass on closed gap, internal copper backing
- Internal root pass on closed gap

External root pass on open gap using STT®offers the advantage of using standard internal line-up clamps and standard API 5L joint preparation. The main disadvantage is its slower welding speeds than other automatic root pass methods.

External root pass on closed gap using internal copper backing method results in high welding speeds, but requires precise joint fit-up to avoid to melting and fusing the copper to the weld.

One of the fastest methods of root pass welding is using a multiple head internal root pass welder integrated with the internal line-up pipe clamp. Conventional constant voltage GMAW-S with vertical-down progression is used. Each head travels only a fraction of the internal pipe circumference. Using a six welding head internal welder, the heads are grouped into two fixtures.

The first group of three heads welds half of pipe circumference. When the first half is completed, the second group of three heads starts welding the other half. By using multiple simultaneous arcs, the root welding time is reduced, increasing the effective welding travel speed.

For consistent automatic welds, tight joint tolerances are required. Also, compound bevel and narrow groove joint designs are usually employed to minimise the weld volume (Figure 2). This further reduces welding times. For these reasons, automatic welding projects commonly have on-site bevelling of the pipe ends.

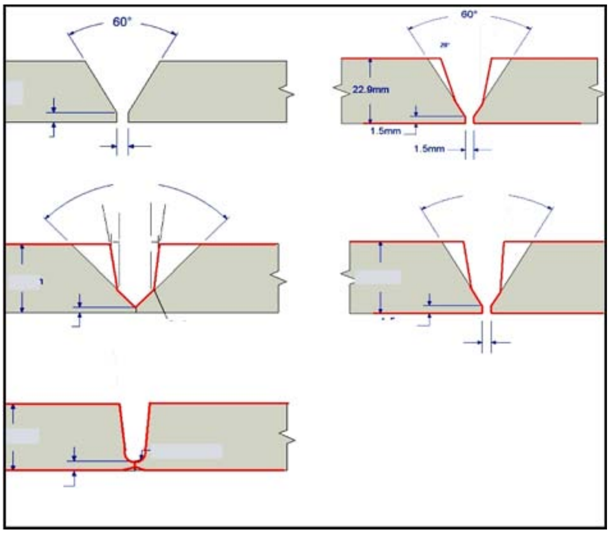


Figure 2: Joint Designs used for Manual, Semiautomatic, and Automatic Welding

FACTORS AFFECTING ROOT PASS SELECTION [1]

They are many factors that influence the choice of the root pass method. These include the factors listed below and detailed in the following sections.

1. Pipe Strength. While cellulosic electrodes are suitable for low strength pipe, higher strength pipe and weld metal that require low hydrogen electrodes to reduce to minimize cracking.

2. Maximum root hardness. Often, a lower strength “under-matched” electrode is used for the root pass. This lowers the weld hardness, reducing the cracking tendency. Also, in corrosive applications, root hardness often needs to be controlled to meet maximum specified value.

3. Weld Metal Toughness. When Charpy V-Notch impact toughness testing is required at the root location, proper root electrode selection is important to obtain desired properties. Also, root pass properties are important when conducting full-thickness Crack Tip Opening Displacement (CTOD) tests.

4. Diffusible hydrogen. Some requirements specify only electrodes which meet a certain maximum weld metal diffusible hydrogen level may be used. In this case, cellulosic electrodes are usually prohibited.

5. Strain aging. For applications such as pipe spooling and ground thaw/seismic design requirements, the weld zone may subject to plastic strains. Careful root pass electrode selection may be needed to ensure that the weld zone overmatches the base metal and satisfies the post-strain mechanical test requirements.

PIPE STRENGTH

Over the last 10 years, API 5L X60 and X65 has been the dominant specified line pipe grade. Historically, these grades have been successfully welded with cellulosic electrodes. However in the past few years, yield strengths much higher than the API minimum have been observed (Table 2). X65 with actual yield strength of 596 MPa has been observed. API allows a yield strength range of 448-600 MPa under the requirements for 5L X65 Product Specification [4] Level 2 (PSL2). This increase in strength has caused some many issues, especially when using cellulosic electrodes that are sensitive to cracking on higher strength steels.

It is usually recommended to weld high strength steel with low hydrogen electrode for all passes. However, past experience has shown that high strength steel pipe can be successfully welded using a cellulosic root and hot pass with proper preheat and filling the remainder of the joint with a low hydrogen electrode.

Table 2: [4] Observed Strengths in X60-X80 Line Pipe

Line Pipe Grade API 5L PSL2	Min Yield MPa	Max Yield MPa	Actual MPa	Min Tensile MPa	Max Tensile MPa	Actual MPa
X65	448	600	586	531	578	
X70	483	621	609	565	758	680
X80	552	690	664	621	827	745

LONGITUDINAL AND SPIRAL SEAM WELDED PIPE

Steel line pipe can be manufactured by many different methods. The two most popular methods of manufacturing large diameter steel line pipe are longitudinal seam submerged arc welding and spiral (or helical) seam submerged arc welding. These two types of line pipe can be discerned by locating the pipe weld seam reinforcement and seeing if it runs longitudinal or helical relative to the pipe axis.

Longitudinal seam submerged arc welded pipe is the most common type of steel line pipe used for cross-country pipelines. However, spiral seam submerged arc welded pipe has been rapidly gaining in popularity. It is often lower cost than longitudinal welded pipe and can be supplied in longer lengths, which lowers pipe laying time and costs. However, sometimes spiral pipe has problems with ovality at the pipe ends and may result in excessive offset (Hi-Lo) of the pipe walls during welding. If not properly controlled, this offset results in difficult welding and possibly inadequate penetration. Increasing the internal line-up clamping pressure helps reduce ovality, but increases the risk of stress cracks, especially when using cellulosic electrodes.

PIPELINE DIAMETER AND WALL THICKNESS

Pipe diameter plays a major role on how long it will take to weld a root pass. Larger diameter pipe e.g. 1220mm, for example, takes longer to weld than a small diameter e.g. 609mm employing the same process. Thus, larger pipe diameters usually correlate to slower pipe laying speeds. To offset this, the number of root pass welders (or arcs) may be increased, or a faster root welding process may be selected.

Increasing pipe wall thickness results in higher hardness in the weld zone and increases the tendency of weld cracking. This is primarily due to the following factors:

To obtain the same strength, thicker wall pipe tends to have more alloys and a higher carbon equivalent than thinner wall pipe. These results in a harder weld and weld HAZ.

Thicker steel cools the weld faster, which increases the weld zone hardness. Thicker pipe is more rigid, resulting in higher residual stress. It is more difficult for hydrogen to escape the weld zone due to faster cooling and increased distance it need to travel to the surface. Therefore, one should not assume that a root pass method, which worked successfully on thin wall pipe, would perform exactly the same on thicker wall. Higher preheat temperatures, low hydrogen consumables, or a different welding procedure may be needed.

PIPELINE TERRAIN AND ENVIRONMENTAL CONDITIONS

The pipeline laying speed is highly dependent on the terrain and environmental conditions. Fast laying speeds are usually obtained on flat, dry plains. Conditions such as rocky, hilly, or wet terrain, bad weather, river and road crossings slow the pipe laying speed. If the conditions are present for slow laying speeds, it may not be of much benefit to select a fast root pass method.

Environmental conditions

Irregular Terrain

LENGTH OF PIPELINE

Generally, automatic welding is more cost effective on longer, larger diameter pipelines, usually above 50 km in length and above 36 inch in diameter. On small projects, high initial capital costs may not be recovered. Rental costs have a minimum rental period and if the project runs into delays, this can be costly if not properly calculated in the original bid.

INSPECTION

Increasing the root pass welding speeds necessitates faster weld inspection speeds. The traditional method of radiography inspection trails production welding by approximately ½-1 day. This is due primarily to the health and safety precautions that must be taken when working with a radioactive material or a radiation source. This inspection delay may be satisfactory at traditional root pass laying rates of 40 joint joints per day. However, automatic internal root welding systems can lay pipe in excess of 200 joints per day. This requires a faster inspection method that can keep up and follow closer to the production welders.

Automatic ultrasonic testing (AUT) has become the preferred method for inspecting automatic pipeline girth welds. Radiation hazards have been eliminated. AUT inspection crews can work in close vicinity to others, including the welding and pipe coating crews. It is also fast, with the inspection data automatically processed by computer. It is better than radiography in detecting non-volumetric planar flaws, like lack-of-fusion, which is more likely with automatic GMAW processes. Also, recent advances in AUT such as Time of Flight Diffraction (TOFD) and Phased Array, allow detection of smaller defects and can more accurately locate and size defects. With faster inspection speeds the time to bury the pipe into the ground is reduced, lowering spreads costs.

LOGISTICS

It is common knowledge that the more sophisticated the welding system the more support functions are required to ensure the critical path keeps moving. In the rental scenario more equipment needs to be on site in case of break down and this can be costly adding to the expense of spare parts and pipe-facing. Much of the pipeline welding done today is in the emerging economies of the world, often in remote inhospitable climates and must draw on local labor pools for welders. With the decrease in experienced pipeline welders (manual metal arc) and the increase in Automatic welding training is essential for a successful pipeline project. Research into Local labor markets may not always give the desired results and so training should be a planned item and not a reactive action. It is essential to ensure any problems are sorted out in the yard not on the Pipeline.

COSTS

Rental

High outlay (minimum hire period), no investment return but cost offset by faster spread removals. Liability high for unskilled labor force and repair rate which would not be covered by the rental of the equipment.

CAPITAL OUTLAY (TO BUY)

Manual Metal Arc - relatively low, low maintenance low risk, high skill, labor intensive, repair rates can be high.

Semi Automatic - relatively low compared to an Automatic welding spread, Can use other hybrid process for fill and cap passes.

Automatic - high capital outlay, expensive logistical support, due to pay back limited to large dia and long lengths.

OUTURN COSTS [1]

This is what is described, as costs not put in the original bid. These costs will usually be things not foreseen like, failed welding procedures, slower welding speeds due to increased pre-heats/interpass temperatures, higher than expected repair rates, bad weather, bad ground conditions for the processes chosen, costs not foreseen in rental charges or logistical support for new capital equipment. It would appear that winning the project at all cost has hidden danger and higher risk. In many cases each contractor will work on a low bid margin but how this translates into profit given the fact outrun costs will occur is purely down to risk management.

CONCLUSION [1] [2]

There are more choices than ever for root pass welding. The best choice depends on many factors such as weld properties, pipe strength, pipe size, pipeline length, terrain and the most practical welding solution. The best choice will result in safe efficient pipeline construction with fast welding speeds, minimal defects, and cost-effective pipe laying.

Welding speed is the critical component and must be seriously considered when looking at the welding of the root pass and subsequent fill passes. The pace of pipe laying is determined by how quickly the root pass can be done. While some time can be gained by putting more operators on this pass, there is a practical limit to this approach. Speed is needed to maintain schedules and control equipment-leasing costs. The more expensive equipment tends to be faster but cost control is more difficult and it is not so economical on shorter pipeline distances.

The welding process chosen must be adaptable to contend with the regional labor available and all the adverse conditions of weather including wind, temperature extremes, and moisture. The necessary skills needed either exist or can be easily learned. Semi Automatic (STT®) is learned more quickly that for Cellulose root passes.

When all of the above factors are considered, two welding processes emerge as the leading processes for root pass welding, shielded metal arc welding (MMA) and gas metal arc welding (GMAW). In the case of shielded metal arc welding, there are advantages to using cellulose electrodes in the vertical down direction but with the increase in stronger pipe grade and the H2 levels generated are not safe any more. Low Hydrogen stick electrodes provide the required H2 level but the welding speed is too slow and impractical for the main pipeline string. [3]

The Automated process choice of today for root pass welding is GMAW and is generally used with either an internal copper backup ring, or, if the diameter is large enough, an internal welding system. Both of these approaches add complexity to field welding and impose certain restrictions on the use of traditional GMAW transfer modes. With backup rings there is the possibilities of unacceptable copper pick up and indications on AUT in the root pass areas. With internal welding systems there is a minimum pipe diameter below which the systems are not practical or cost effective and with this system root repairs are not so easy.

The three different solutions discussed within GMAW that give acceptable root pass welds can be classified into 3 main groups,

1. External Open root Pass welding – STT®
2. External Closed gap – copper shoe backing ring- single and twin wire
3. Internal Root Pass Welding – multi head

It is still apparent that High production welding processes have inherent tendencies to produce Lack of Fusion, which in turn questions whether a production weld is acceptable or not. To avoid such concerns improved inspection methods along with ECA will play a vital role in determining acceptability. For the traditionalists in the Industry a welding solution that would produces cleaner welds would be a more profitable objective. The goal for an ideal welding process should be one that would allow welding of a root bead without backup rings and internal systems and would produce a root bead with sound weld metal with just enough buildup to insure a full thickness weld. This weld would also have no internal undercut, lack of fusion or porosity and would give improved mechanical properties.

The risk taken in Pipelines is surprising and experience of lessons learned from the last project should be part of evaluating the risk of the next project. Welding the pipeline the fastest way on paper does not always turn out to be the best financial return. The more sophisticated the equipment the higher the risk. The best choice of root pass will employ the minimum risk and should be selected for quality and productivity but should also incorporate risk assessment on whether the optimum process choice can produce the project needs. [1]

Whatever process is used for the root pass it is clear that there are many more influences than might have been previously thought of or discussed. The project objectives are clear, the contractor will make more money if he welds faster but if the full implication of the root pass or the weld is not fully understood then money will be lost and not made.

REFERENCES

[1] Field experience by James Lamond Lincoln Electric Europe
[2] Ken Lee Lincoln Electric USA, joint editor of Paper-USA practice
[3] TWI PR-164-9330 Aug 1996. EVALUATION OF LOW HYDROGEN WELDING PROCESSES FOR PIPELINE CONSTRUCTION IN HIGH STRENGTH STEEL
[4] ASME API 5L PSL 2
[5] First presentation of this paper -The Dutch Welding Institute- Jan Hilkes, Lincoln Electric 2006.