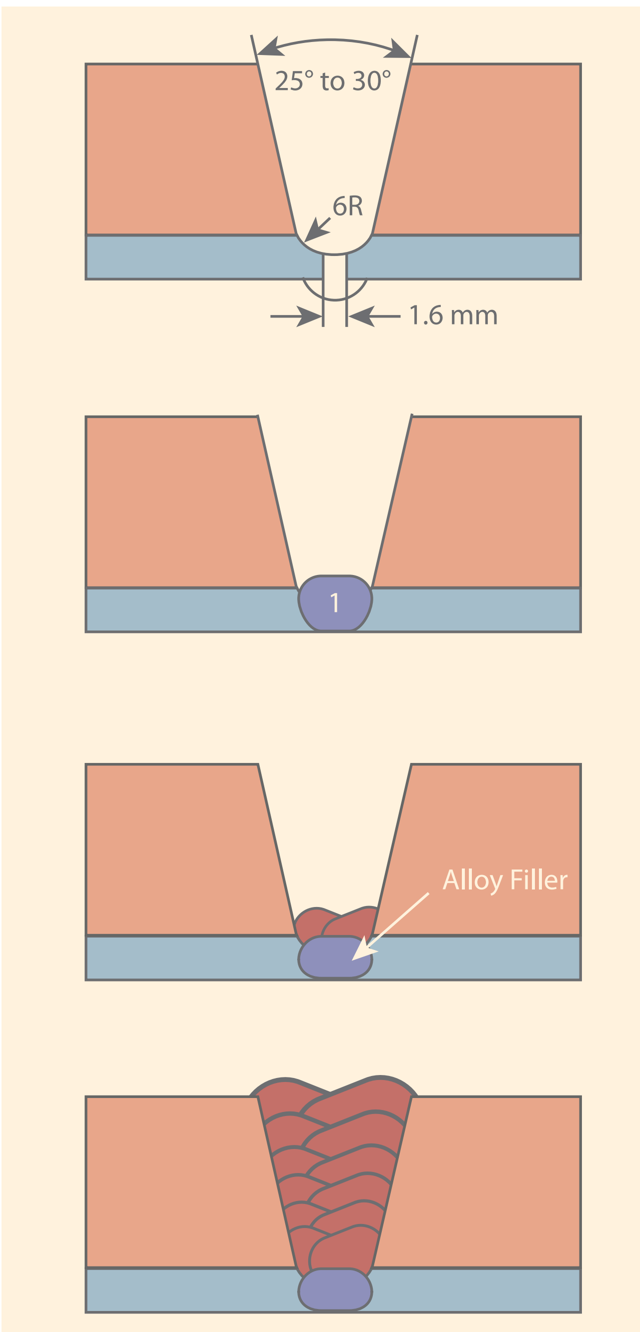
Successful welding of this critical root weld is highly dependent upon a good tolerance on the roundness of the pipe. If automatic GTAW with a closed root is to be used, the maximum misalignment, often called "hi-lo", which can be tolerated is 0.5mm which therefore requires a very tight tolerance on the pipe internal diameter. Slightly wider tolerances may be allowed on larger diameter pipe where pipe clamps can be used to round the pipe before welding. Mismatch of the root can be more easily accommodated by manual GTAW where a root gap in used.

**FIGURE 26. Schematic bead sequence for welding of clad steel with single-sided access.**




The use of GTAW with good back shielding with inert gas produces an inner bead free of flux or oxides and undiluted with steel, thus offering maximum corrosion resistance. The second pass, also with alloy filler, will be diluted by the carbon steel and therefore it is important that the heat input is not high enough to remelt the root pass entirely otherwise carbon steel may be mixed into the root. Heat inputs of 0.9 -1.2 kJ/mm are recommended. Internal gas shielding should be maintained to prevent oxidation of the hot root. Subsequent passes may be completed with the alloy filler using GTAW, GMAW or SMAW techniques.

Alternatively a buffer layer of pure iron can be deposited after which the weld can be completed with the appropriate steel filler. Direct change to steel filler without the intermediate iron buffer would result in a hard martensite formation in the weld where the alloying elements from the alloy deposit are mixed into the higher carbon content steel deposit.

In many cases changing electrodes during welding is not felt to be practical and so the welds are completed with alloy filler. The economic benefit of using a buffer layer would be particularly advantageous for heavier wall thickness with many weld passes.

In the case where alloy fillers are used throughout the weld, the strength should be at least equal to the backing steel. The as-deposited weld yield strength of 309MoL is equal to X60 grade steel and Alloy 625 will meet the X65 requirements.

Where there is double-sided access, then the weld can be completed in the steel backing material (see typical preparation, **Figure 27**). The root can then be ground out from the inside surface and the clad layer completed using any overlay welding technique.

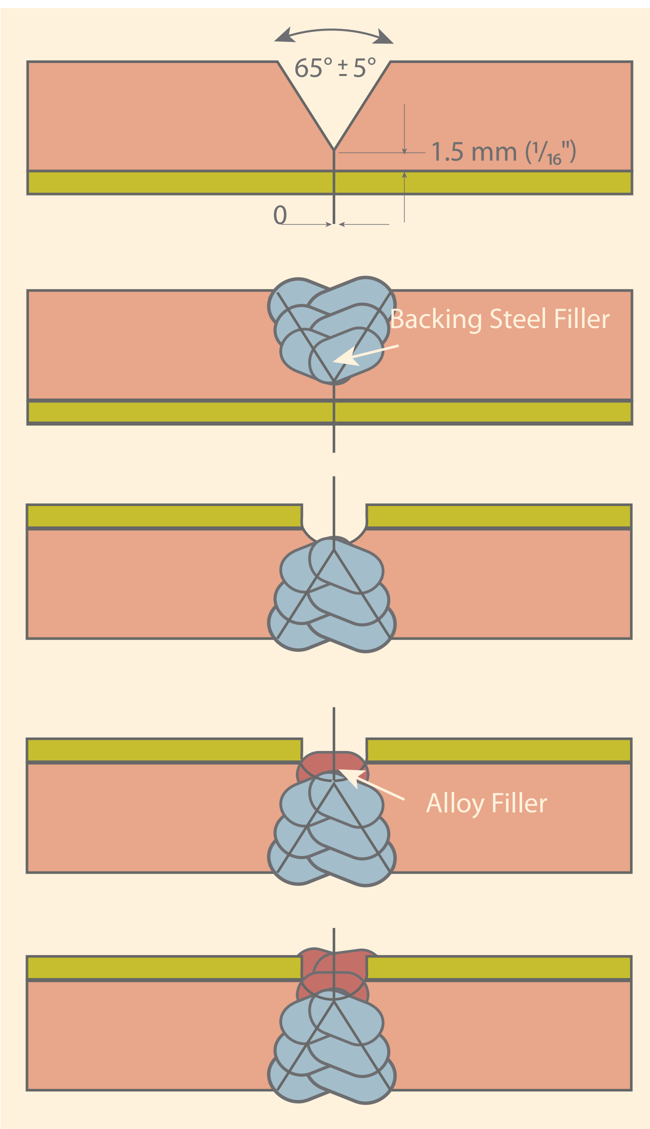
### 6.1 Field Welding Challenges

It is sometimes found after making the weld preparation that the nose of the bevel does not lie entirely within the clad layer but includes some backing steel. This can be checked by etching the bevel with copper sulphate or copper ammonium chloride solution. It may be possible to grind off the carbon steel but if the nose is then too small the weld preparation will need to be built-up by initially weld overlaying the nose and then remachining.

Early lined pipe installation always required the lining to be rewelded to the pipe following the cut-out of girth welds. More recent project experience indicates that where the repair weld is made quickly after rebevelling the pipe end (so there is no risk of moisture getting into the gap) the repair girth weld can be easily done without the re-attachment of the liner.

During a number of projects in different parts of the world, fabricators have commented on a problem of arc blow whilst welding clad pipe. Arc blow is a much more acute problem for welding clad and lined pipe than when welding carbon steel pipe. It is therefore considered to be primarily a problem related to the use of an austenitic (non-magnetic) filler material, in a magnetic steel pipe. As the joint is filled with austenitic material, the lines of magnetic flux have to deflect around the deposited metal, causing distortion to the magnetic field.

**FIGURE 27. Schematic bead sequence for welding of clad steel with double sided access.**




The extent to which these problems can arise is dependent upon many parameters:

- **The joint design.**
- **The joint gap.**
- **The inherent magnetism of the pipe ends and the way they interact when brought together at the joint.**
- **The selected welding process (some having a stronger or stiffer arc and therefore less susceptible to deflection).**
- **The welding parameters which influence arc characteristics.**
- **The type of welding power source.**

Notwithstanding this phenomenon, pipelines have been laid without excessive repair rates in most cases. Steps which help are to purchase pipe with residual magnetism below 20 Gauss and also to dynamically remove the magnetic field whilst welding using specialist demagnetizing equipment.

The ultrasonic inspection of clad welds presents a challenge because of the refraction of the beam as it passes from the ferritic backing steel into the austenitic weld metal (in a typical fully-austenitic weld deposit). This results in some error in interpretation of any defect dimensions and location. Confidence in identifying the critical root defects is not as high as in welds with a homogeneous composition. Specialist inspection methods can overcome these problems but it is advised to use the weld qualification trials as an opportunity to calibrate any system for use in the production phase.

## 7. ENGINEERING WITH CLAD STEEL

The previous sections of this paper have described the wide range of products available in clad form and given examples of where clad steel has been applied. By utilising the full range of available clad products a project could be completely engineered in clad steel from the reservoir to the export line using production tubing, wellhead, valves, flowline, vessels, piping and heat exchangers made from steel clad by appropriate methods.

A summary of various methods for making clad products and their dimensional availability is given in Table 5. The sizes given are those which are readily available although