

HOW TO WELD

AVESTA SHEFFIELD 904L

by Björn Holmberg, M.Sc.

MATERIAL DESCRIPTION AND PRODUCT STANDARDS

Avesta Sheffield 904L is a highly-alloyed austenitic low-carbon stainless steel. The steel grade is developed for non-oxidizing solutions such as sulphuric acid, but is also recommended in neutral chloride-containing solutions (pitting) and in situations where there is a risk for crevice corrosion and stress corrosion cracking.

Avesta Sheffield 904L is a fully-austenitic stainless steel with good weldability. Due to its high molybdenum content and specially designed welding consumables with low impurity levels, hot crack formation during welding can be avoided despite the fully austenitic filler metal.

The typical composition is: (%)

	C	Cr	Ni	Mo	N	Others
904L	0.01	20	25	4.5	0.06	Cu

Avesta Sheffield 904L complies with the following standards:

SS 2562, DIN 1.4539, ASTM N08904 and NF Z1 NCDU 25-20.

The following product standards are complied with: Swedish National Board of Occupational Safety and Health, Vd TÜV WB 421, ADW2, ASTM B625, ASME SB-625, ASTM B649, ASTM B673, ASME SB-673, ASTM B674, ASME SB-674, ASTM B677, ASME SB-677.

FORMING, HEAT TREATMENT AND MACHINING

Hot forming

The grade lends itself easily to hot forming, although it is important that this is carried out in the temperature range 950–1200°C. Higher temperatures will reduce the formability of the steel while also increasing the formation of annealing scale.

It is generally unnecessary to carry out subsequent heat treatment if the final operation is carried out above the recrystallization temperature, i.e. above 900°C, and is followed by rapid cooling. It is also important that the entire component is at this temperature. In the case of partial heating or partially delayed cooling, heat treatment becomes necessary.

Cold forming

904L possesses very good cold formability characteristics. Bending, pressing and other forming operations which occur in equipment fabrication can be carried out in connection with more complicated forming operations such as complex deep-drawing.

The degree of cold working and the ultimate application determine whether annealing of the finished component is necessary, for instance in situations where there may be a risk of stress corrosion cracking.

Heat treatment

904L is quench annealed at 1100–1150°C with subsequent rapid cooling. To obtain rapid cooling in heavy thicknesses water cooling is sometimes necessary.

Machining

Like other austenitic steels, 904L is tough and has a tendency towards work-hardening. This must be taken into account when the steel is machined.

With the right choice of tool and machine data, fully satisfactory machining results can be obtained with this grade.

JOINT DESIGN

Figures 1–8 (page 2) show different joint designs that can be recommended for 904L. The joint is designed in such a manner that full penetration can be achieved without the risk of burn through. Only a small selection of possible joint types is shown here. If the material thickness is greater than 12 mm and it is possible to weld from both sides of the joint, joint design 3–5, for example, can be made symmetrical.

The root bead can be deposited using either GTAW (TIG) or SMAW (covered electrodes). If GTAW is used, backing gas shall be applied at the tacking stage. The root side of a root bead deposited with SMAW shall, as a rule, be cleaned after welding, see page 6. A suitable electrode diameter is 2.5–3.25 mm depending on base material thickness, welding position and accessibility for root-side grinding.

Joint design 1 can be used for single- and double-sided SMAW. If double-sided welding is possible, GMAW (MIG) can also be used.

Joint design 2 is intended for GTAW from one side. Always use backing gas.

Joint design 3 is intended for welding of heavier metal gauges with SMAW or GMAW. If the joint is welded in a vertical-up position with SMAW, the joint opening can be increased to 3 mm. It is a good idea to grind the bottom after tacking to facilitate the weaving motion.

Joint design 4 is used in very thick base metals. The reason for its U-shape is that both the quantity of filler metal and distortion can be minimized. Welding methods: SMAW, GMAW.

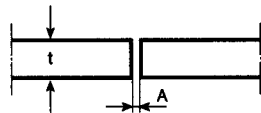
Joint design 5 is intended for SAW. Grinding before welding from the reverse side of the joint facilitates full penetration.

Joint design 6 shows a normal fillet joint with full penetration. In order to achieve penetration the plates must be tacked using SMAW or GMAW, for example.

Joint design 7 is used for SMAW of pipes. To facilitate work in the overhead position, the single-V butt joint can be ground to a U-shape after tacking.

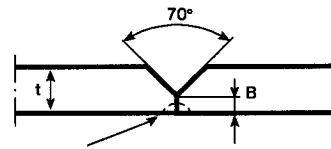
Joint design 8 deviates slightly from what is usually recommended for pipe welding with GTAW. The reason for this is that it is otherwise difficult to achieve full penetration in this steel grade.

JOINT DESIGN 1. Square Butt Joint



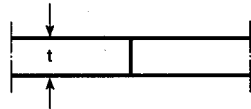
Welding with SMAW or GMAW
 $2 \leq t < 4$
 $A = 1-2 \text{ mm}$

JOINT DESIGN 5.



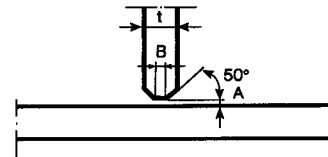
Grinding before reverse side welding
 Welding with SAW
 $9 < t < 12 \text{ mm}$
 $B = 3 \text{ mm}$

JOINT DESIGN 2.



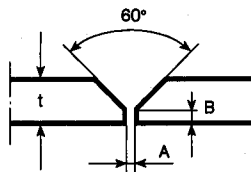
Welding with GTAW
 $1 \leq 2.5 \text{ mm}$

JOINT DESIGN 6.



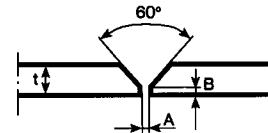
Welding with SMAW
 $4 < t < 12 \text{ mm}$
 $A = 2.5 \text{ mm}$
 $B = 2 \text{ mm}$

JOINT DESIGN 3.



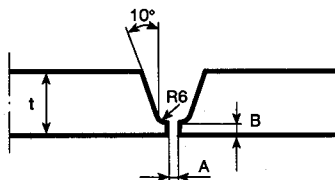
Welding with SMAW or GMAW
 $4 \leq t < 12 \text{ mm}$
 $A = 2 \text{ mm}$
 $B = 2 \text{ mm}$

JOINT DESIGN 7. Single V joint. Tube welding



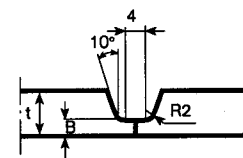
Welding with SMAW
 $4 \leq t < 12 \text{ mm}$
 $A = 2.5 \text{ mm}$
 $B = 2 \text{ mm}$

JOINT DESIGN 4.



Welding with SMAW or GMAW
 $12 < t < 60 \text{ mm}$
 $A = 1.5 \text{ mm}$
 $B = 2 \text{ mm}$

JOINT DESIGN 8. Single U joint. Tube welding



Welding with GTAW
 $3 \leq t < 12 \text{ mm}$
 $B = 1.5-2 \text{ mm}$

Figures 1-8

Excessive weaving, which creates wide molten pools, should be avoided. This causes high heat input and high stresses. The following points should be kept in mind when choosing a joint type:

- it must be easy to achieve full penetration with a good margin of safety.
- it must be possible for the welder to keep slag formation and the weld pool under observation.

The joint design must also enable the operator to arrange an adequate backing gas shield. Root defects can serve as starting points for corrosion or reduce the mechanical strength of the weld joint.

JOINT PREPARATION, CLEANING

Cleaning of joints and adjacent surfaces is normal practice before all welding of stainless steels. Dirt, oils and paint can cause weld defects. Grinding burr must be removed, since it can easily cause incomplete fusion. Common solvents such as acetone and thinner can be used as cleaning agents. Moisture in the joint can cause porosity.

The easiest way to prepare the joint is by means of a metal cutting operation. Manual grinding, if performed carefully, can also give good results. The joint shall be designed in accordance with the guidelines in Figures 1-8. Large variations in joint preparation, leading to different thicknesses of the land, can easily cause welding problems. For the same reason it is important that the gap distance after tacking of the plates is constant, as shown in Figures 1-8.

PREHEATING AND POSTWELD HEAT TREATMENT

Preheating 904L is not normally necessary. It may, however, sometimes be useful when welding outdoors in cold weather, since there is a risk of condensation and resultant moisture problems in the joint groove and in the weld metal. In such cases, the joint and adjacent areas may be heated very carefully. It is very important that the heat is uniformly distributed. Local heating to temperatures higher than 100°C must be avoided, since this can lead to carbon pickup, which can in turn cause intergranular corrosion.

Postweld heat treatment is not normally necessary. If it should become necessary for any reason, this should take place at 1100-1150°C, followed by rapid cooling.

GAS TUNGSTEN ARC WELDING

Equipment

Gas Tungsten Arc Welding (GTAW), commonly called TIG, may be performed manually or by machine. A constant-current power supply should be used, preferably equipped with a high-frequency circuit for starting the arc and a stepless control current decay unit incorporated in the power supply unit. GTAW should be done using direct current straight polarity (DCSP), electrode negative. Use of direct current reverse polarity (DCRP) will result in rapid electrode deterioration.

Choice of filler metal

Avesta 904L filler metal complies with DIN 8556 W.-Nr. 1.4519, and the Swedish Material Standard 20.25 5L Cu. Avesta 904L filler metal is approved by TÜV, among others.

Avesta P5 (AWS ER 309Mo) filler can generally be used for joining 904L to low-alloy steels and carbon steels. In cases where the base material is thin or when joining 904L to other stainless steels, 904L fillers can be used.

In critical situations, for example in very aggressive chloride-containing solutions, an over-alloyed filler, Avesta P12, is recommended.

Weld pool protection

The weld pool in GTA welding should be protected from atmospheric oxidation by inert gas flowing through the welding torch. The turbulence of the inert gas, and the resulting entrainment of air, can be minimized by using a gas diffuser screen (gas lens) on the torch.

Operating procedures should be adjusted to ensure adequate inert gas shielding. Gas flow should precede arc initiation by several seconds and should be held over the weld pool for at least five seconds after the arc is extinguished. If the flow is too low, the weld pool will not be adequately protected. If the flow is too high, gas turbulence may force air into the weld region. Argon backing gas is required on the rear of the joint for all root passes, regardless of joint design. The argon should be welding grade 100% argon, with a purity of at least 99.95% argon.

Approximate flow rates are 12-18 l/min (5-8 l/min if normal gas nozzle) for the electrode and 2-20 l/min, dependent on root volume, for the backing purge. The enclosed volume should be purged a minimum of seven times before welding begins. Argon should be fed in at the bottom and out at the top because of its weight relative to air.

Addition of oxygen and carbon dioxide should be avoided for metallurgical reasons. An addition of helium may also be useful under some circumstances.

There should be regular inspections of O-rings for water-cooled torches and of gas hoses to ensure that only pure, dry shielding gas is delivered to the weld area.

GTAW welding technique

The nonconsumable electrode shall meet the requirements of AWS specification A 5.12. Classification EW Th-2 (2% thoriated tungsten electrode).

Good arc control is obtained in GTAW by grinding the tungsten electrode to a point. Vertex angles of 30-60 degrees with a small flat at the point are generally used. For automatic GTAW, the vertex angle has an influence on penetration characteristics. A few simple tests to determine correct electrode configuration should be made before the actual welding is started.

The joint should be prepared in one of the joint designs shown in Figures 1-8 with attention paid to surface preparation, edge preparation, alignment, root spacing and installation of a backing bar to ensure full argon backing gas coverage while making tack welds and the root pass.

Ignition of the arc should always take place within the joint itself. Any strike scars alongside the joint should be removed by fine grinding.

Tack welds of appropriate length and spacing should be made with full argon shielding. The root pass should be made using Avesta 904L filler metal and the appropriate shielding gas flow. There should be no tack weld at the starting point of the actual root pass weld. To avoid cracking in the root pass related to tack welds, the

welder should interrupt the root pass before a tack weld. He should either grind away the tack completely with a slitting wheel grinder or make the tack shorter by grinding the start and finish of the tack prior to recommencing the root pass. The width of the root gap should be maintained to avoid shrinkage.

The start and finish of the root pass weld should be ground off prior to the start of any filler passes. Straight stringer beads should be used. The metal should be allowed to cool to a temperature lower than 100°C between passes. The joint may be filled using additional passes with 1.6, 2.0 or 2.4 mm diameter 904L filler metal with 100% argon shielding gas. GTA welding generally gives the best results in the flat position, but vertical welds can also be made successfully. The torch should be as near as possible to perpendicular to the workpiece.

Due to high thermal expansion and low thermal conductivity, a great deal of heat is accumulated close to the welding zone. This can cause severe shrinkage stresses and consequently lead to a risk of deformation or, for restrained constructions, a risk of hot cracking. The heat input should therefore be limited to max. 1.5 kJ/mm, and the interpass temperature to max. 100°C.

Excessive deviation from the perpendicular may cause air to be drawn into the shielding gas. The filler wire should be kept clean at all times. Filler wire should be stored in a sealed container when not in use.

After welding, heat tint, spatter and slag should be removed by fine grinding, using as fine an abrasive as possible while still removing heat tint within a reasonable time. Abrasive blasting with 75–100 micron glass beads is also acceptable. Carbon steel brushes must not be used. Abrasive blasting particles should not be used on carbon steel parts. These precautions are designed to prevent iron contamination of the surface that might initiate pitting in aggressive chloride environments.

Alternatively, heat tint may be removed by the use of pickling paste or acid treatment followed by thorough rinsing of the acid from the metal.

GAS METAL ARC WELDING

Equipment

The MIG welding method can be performed using three different types of arc transfer:

a) Short-circuiting transfer

This type of arc is used for welding materials in thickness up to 3 mm. Short-circuiting transfer produces a low heat input and is particularly useful for welding thin sections where there is a risk of deformation if the heat is too high. This type of arc is also suitable for positional welding.

b) Pulsed arc transfer

This method requires a power source which makes it possible to achieve a pulsating arc. The principle uses a low basic current interspersed with pulses of relatively high current. The current is at its highest during spray transfer and lowest in the globular range. This type of arc has all the benefits of the spray transfer method, but produces a lower heat input, thus making the method suitable for all welding positions.

c) Spray transfer

Spray transfer is accompanied by high heat input but it gives a stable arc and high deposition rates. It is generally limited to flat-position welding.

GMAW should be performed using direct-current reverse polarity (DCRP)—electrode positive.

Choice of filler metal

GMAW uses a consumable electrode in the form of a continuous solid wire, which is usually supplied on a layer wound spool and fed through the GMA torch by an automatic wire feed system.

Avesta 904L welding wire is approved by TÜV.

When Avesta Sheffield 904L is GMA-welded, two different kinds of shielding gases can be used. Either one consisting of 69% argon, 30% helium and 1% oxygen or a gas of the Ar + 0.03% NO-type.

Short arc welding is used for thin base material of less than about 3 mm in thickness for depositing root runs and for welding out of position.

Shielding gases with helium always lead to more soot on both sides of the weld than argon/argon-oxygen gases. This soot can, however, be easily removed by brushing. For optimal weldability with short arc transfer mode with helium mix gases, some reduction of inductance might be necessary. Another effect on welding with helium gases is that the arc gives a deeper penetration, which the welder has to take into account when welding thin material.

There should be regular inspections of O-rings in water cooled torches and of gas hoses. Welding in the presence of air drafts, regardless of welding position, should be avoided.

Typical welding parameters of globular transfer arc using 70 He/30 Ar shielding gas, 13–18 l/min are:

Wire diameter mm	Current A	Voltage V
1.0	160–210	27
1.2	200–260	28

Typical welding parameters for short circuiting arc transfer using the gas mix 69Ar/30He/1O₂, 11–15 l/min are:

Wire diameter mm	Current A	Voltage V
1.0	80–140	18–21
1.2	100–160	19–22

For MIG-welding the heat input should be limited to max. 1.5 kJ/mm, and the interpass temperature to max. 100°C.

GMAW welding technique

The joints should be prepared in one of the joint designs shown in Figures 1–8 with attention paid to surface preparation, edge preparation, alignment, root spacing and installation of a backing bar to ensure full argon backing gas coverage while making tack welds and the root pass.

Ignition of the arc should always take place within the joint itself.

Tack welds of appropriate length and spacing should be made with normal gas shielding. The root pass should be made using Avesta 904L filler metal with the appropriate shielding gas flow. There should be no tack weld at the starting point of the actual root pass weld. To avoid cracking in the root pass related to tack welds, the welder should interrupt the root pass before a tack weld. He should either grind away the tack completely with a slitting wheel grinder or make the tack shorter by grinding the start and finish of the tack prior to recommencing the root pass. The width of the root gap should be maintained to prevent shrinkage.

The start and finish of the root pass weld should be ground prior to the start of any filler passes. Straight stringer beads should be used. The metal should be allowed to cool to a temperature lower than 100°C between passes. The joint may be filled using additional passes with 1.0, 1.2 or 1.6 mm diameter Avesta 904L filler metal with 100% argon backing gas. GMA welding generally gives the best results when performed in the flat position, but vertical welds can also be made successfully. The torch should be as near as possible to perpendicular to the workpiece. Excessive deviation from the perpendicular may cause air to be drawn into the shielding gas. The filler wire and guide tube should be kept clean at all times. Filler wire should be stored in a sealed container when not in use.

After welding, heat tint, slag and spatter should be removed by fine grinding, using as fine an abrasive as possible while still removing heat tint within a reasonable time. Abrasive blasting with 75–100 micron-soda lime glass beads is also acceptable. Carbon steel brushes must not be used. These precautions are designed to prevent iron contamination of the surface that might initiate pitting in aggressive chloride environments. Alternatively, heat tint may be removed by use of pickling paste or acid treatment followed by thorough rinsing of the acid from the metal.

SHIELDED METAL ARC WELDING

Equipment

Shielded Metal Arc Welding (SMAW), commonly called manual metal arc welding, is performed using a constant-current power supply. SMA welding is done using direct current reverse polarity (DCRP)-electrode positive.

Choice of filler metal and use

SMA welding uses a consumable electrode in the form of a core wire with a flux covering. The covering provides arc stability, shields the molten metal during arc transfer and protects the weld during solidification.

Avesta 904L AC/DC is a suitable general-purpose rutile electrode with medium high metal recovery (140%).

The rutile electrode Avesta 904L-PW is designed for out-of-position welding and for root runs.

Avesta 904L AC/DC is approved by institutions such as TÜV.

Avesta 904L AC/DC and 904L-PW AC/DC complies with DIN 8556, W.-Nr. 1.4519, NF A81-343 and the Swedish Material Standard E 20.25.5L Cu.

Electrodes are supplied in air-tight containers as moisture in the electrode covering can produce weld porosity. Once the container is opened, the electrodes should be stored in a commercial electrode-oven heated to at least 100°C in order to keep the covering dry.

The operating current required to achieve good welding characteristics increases with increasing electrode diameter. Typical SMA welding parameters are:

Electrode diameter mm	Current A
2.0	35– 60
2.5	50– 80
3.25	80–110
4.0	100–150

Weld pool protection

In SMAW, the weld pool is protected by gases and slag from the electrode covering. To maximize this protection, the welder should maintain as short an arc as possible. "Long arc", an increased gap between electrode and workpiece, can lead to weld porosity, excessive oxides, excessive heat input and reduced mechanical strength.

SMAW welding technique

The root pass should be made with 2.0 or 2.5 mm diameter electrodes. Larger electrodes may be used for subsequent filler passes. Ignition of the arc should always occur within the joint itself. Any strike scars and spatter alongside of the joint should be removed by fine grinding.

SMAW should not be used to weld parent metal of 904L less than 2 mm in thickness. For optimal speed and economy, the workpiece should be maintained in the flat position. The electrode should be held at 20 degrees (drag angle) from the perpendicular with the electrode grip inclined toward the direction of travel. The metal should be deposited in a straight stringer bead with a width of weave not exceeding twice the electrode diameter. The current should be set just high enough to obtain a smooth arc and good fusion of weld to parent metal.

The start and finish of each filler pass should be ground off prior to the start of the next filler pass. End crater cracks could become starting points for pitting corrosion. The metal should be allowed to cool to a temperature lower than 100°C prior to the start of the next filler pass. All slag material must be removed from each filler pass. After welding, heat tint should be removed by fine grinding, using as fine an abrasive as possible while still removing heat tint within a reasonable time. Abrasive blasting with 75-100 micron soda-lime glass beads is also acceptable. Carbon steel brushes must not be used. These precautions are designed to prevent iron contamination of the surface that might initiate pitting in aggressive chloride environments. Alternatively, heat tint may be removed by use of pickling paste or acid treatment followed by thorough rinsing of the acid from the metal.

When SMA welding is used for the root pass, the root side should subsequently be ground smooth. All weld spatter, slag and heat tint should be removed.

SUBMERGED ARC WELDING

Submerged arc welding of fully austenitic stainless steels should be carried out in such a way that fusion is minimized and that the weld width/weld depth should be 1.5:1 to 2:1. If these rules are followed, Avesta Sheffield 904L can be submerged arc welded without risk for hot cracking.

We recommend the use of 2.4 mm 904L wire and Avesta Flux 801. When thick base material (>10 mm) is to be welded we recommend a maximum of two beads on each side before turning to the other side. In this way, small surface cracks due to high deformation stresses can be avoided.

Where highly restrained welding conditions cannot be avoided the use of Avesta Flux 805 may be used as an alternative to provide extra protection against micro-fissures.

The following example of welding parameters can be applied to 2.4 mm wire. The heat input should be limited to 1.5 kJ/mm.

Current A	Voltage V	Speed cm/min
300-430	27-33	45-60

DISTORTION

Methods of minimizing welding distortion of 904L differ slightly from those of the common austenitic grades due to higher thermal expansion and low thermal conductivity. Good practice includes proper fixturing, cross supports, bracing, staggered bead placement and weld sequence, etc. The edges of the plate or sheet should be squared, aligned and tacked prior to welding. Low heat input minimizes distortion.

REMOVAL OF DIRT, SLAG AND OXIDES

Oxide tarnish, heat tint and other surface contamination can be removed by mechanical or chemical methods, ideally a combination of the two. Mechanical methods include fine grinding and polishing and abrasive blasting with 75-100 micron soda-lime glass beads. Subsequent chemical cleaning is not obligatory after either of those methods, but is good practice since it guards against contamination from the mechanical cleaning medium.

Chemical cleaning is readily accomplished using a pickling solution of 20% nitric acid and 5% hydrofluoric acid in water, or commercially available solutions or pastes with similar ingredients.

Proper precautions must be taken when handling pickling solutions and pastes. Ventilation is required to remove fumes. Protective clothing, face shields and rubber gloves must be worn. Proper environmental procedures are required for the disposal of wash liquors from pickling operations.

SKILL, INSPECTION AND QUALITY ASSURANCE

Manufacturing components using Avesta Sheffield 904L is not significantly different from manufacturing in e.g. 316L.

In order to achieve optimal properties in the weld joints, the welder and other concerned personnel should

therefore be informed of the special aspects of fabricating and welding fully austenitic stainless steels. It is often expedient to prepare a written welding procedure and have the welders carry out a trial welding procedure before they begin the actual welding work.

Since 904L is often used in components where severe corrosion conditions are encountered, the welded joints must be inspected carefully. Incomplete fusion, incomplete penetration, a poorly cleaned root side, spatter and strike scars must be remedied.

Suitable non-destructive testing methods are X-ray inspection, liquid penetrant inspection, hydrostatic testing, and leak detection. Destructive testing can be carried out in the form of bending tests and impact tests.

In order to ensure a good level of quality, welding should be carried out in accordance with predetermined fabrication and inspection plans, by trained and skilled operators.