The Welding Of Stainless Steels

A basic guide to the technical considerations, techniques and standards for the welding of stainless steels

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Safety Precautions in the Welding Workshop

When fabricating in shop or site conditions, certain minimum safety precautions must be taken to protect yourself and others.

1. Eye protection is essential. Warning signs should be posted in all welding areas.
2. Bare skin must not be exposed to any type of arc radiation. Cover up hands, wrists, neck and face.
3. Working areas must be screened off so that arc radiation does not affect other people.
4. Correct filter lenses must be used in helmets and hand shields; shade 8 for 60 Amps and less, shade 10 up to 160 Amps and shade 12 up to 250 Amps. When welding with Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) processes, increase shade darkness by one step for each amperage range.
5. Adequate ventilation must be ensured when working in confined spaces.
6. Never work alone in potentially dangerous situations.
7. Fume extraction facilities and masks should be provided when welding or cutting.
8. Fume extraction may become mandatory, especially when using heavily coated electrodes and flux-cored processes. In case of doubt, consult an expert.
9. When cutting or welding in, or on, any container such as a drum or tank which has previously contained any chemicals of flammable liquid, written clearance to proceed, after all necessary precautions have been taken, must first be obtained from

your safety officer. Before entering a vessel of drum (after having established that it is complete safe to do so), attach a safety harness and line to yourself and have someone stand watch outside with a fire extinguisher.

10. Always work in dry conditions. Wet floors and shoes are dangerous when welding.
11. Attach yourself to a safety harness and line when working above floor level, in order to protect yourself from a fall should a shock occur.
12. Know where the fire extinguishers are located and understand which type to use for each class of fire.
13. Do not weld where the vapours from degreasing solvents are present. The heat and rays of the arc may react with solvent vapours to form phosgene – a highly toxic gas.
14. Reflections from walls and polished stainless steel surfaces can be dangerous. Walls can be painted green or blue to reduce glare.
15. When performing any maintenance operation on welding/cutting torches or power sources, ensure that the equipment is switched off. Shut down and disconnect from the power supply.
16. Do not abuse high pressure gas cylinders. Ensure that they are chained to the work station so that they cannot fall. Cylinder valves should be hand-tight only; do not use a hammer to open and close them. When moving a cylinder, ensure that the valve is closed and the valve guard on.
17. Use the safety clothing and shoes which should be provided.
18. Lighters and matches must not be allowed in the working area nor must they be carried in clothing.
19. Synthetic material clothing should not be worn as these tend to burn easily and melt onto the skin.
20. When handling work pieces with sharp edges, leather working gloves should be worn.
21. The work place should be neat and tidy at all times.
22. Never use drugs or alcohol. People using such substances are a danger to themselves and other.
23. Use ear muffs or ear plugs where necessary. Excessive noise can cause permanent hearing loss and may affect other bodily functions and behaviour. Plasma cutting van produce very high noise levels, and thus may require specific attention to achieve a comfortable working environment.
24. Pickling acids are extremely dangerous and contact with eyes and skin should be avoided at all times. Protective clothing is recommended when working with acids.
25. **BE AWARE AT ALL TIMES.**

What is a Stainless Steel

The term 'stainless steel' is defined as a steel, i.e. an iron carbon alloy, containing a minimum of 11% chromium (Cr) and contains iron (Fe) in amounts ranging from 48% - 85%.

Stainless steels are used in a wide variety of applications where conventional mild steel cannot perform, e.g. conditions such as wet and dry abrasion, chemical attack, elevated or cryogenic service conditions, and wherever bright, shiny, clean and hygienic surfaces are needed, such as the food industry.

Because of the range of applications and the many types of stainless steel, it is necessary to understand the five groups which make up the family of stainless steels.

These groups are:

- Ferritic
- Austenitic
- Duplex
- Martensitic
- Precipitation Hardening

Ferritic Stainless Steels

Common grades include 441, 430, 409 and 3CR12. These steels are essentially plain chromium steels, containing 12% - 18% Cr.

The material has the following characteristics:

- Magnetic
- Cannot be hardened by heat treatment

The Typical applications for this material are exhaust systems, kitchen sinks and cutlery.

Welding is best suited to thin gauges.
Welds may be produced on thicker sections but grades 441, 430 and 409 have poor weldability and tend to become brittle. This limitation has led to the development of a material known as 3CR12. This semi-ferritic steel is available in plate form, and is readily weldable even in thick sections. 3CR12, which was developed in South Africa, has found applications throughout the mining and construction industries both locally and internationally.

Austenitic Stainless Steels

Common grades are:

- 304, 304L
  Standard chromium nickel stainless steels
- 321, 347
  Stabilised stainless steels
- 316, 316L, 317
  Stainless steel containing molybdenum
- 309, 310
  High temperature alloys

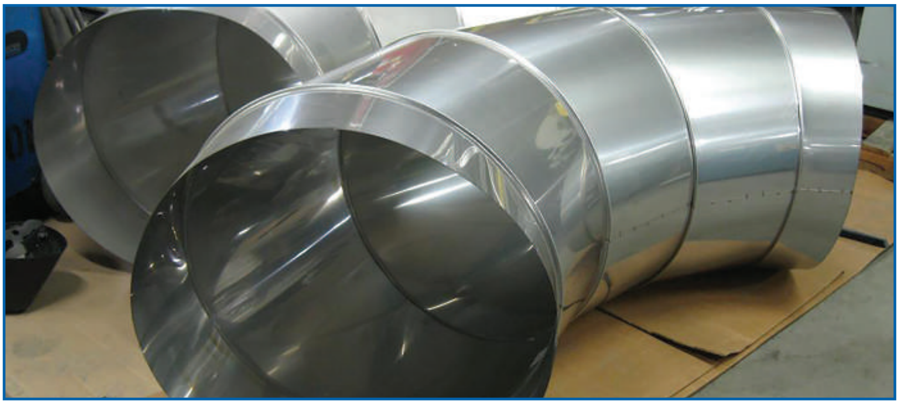
When nickel (Ni) is added to stainless steel in sufficient quantity, the structure changes from ferritic to austenitic. The basic 18/8 composition of austenitic stainless steels is 18% Cr and 8% Ni. Molybdenum (Mo) may be added to give additional corrosion and pitting resistance. Titanium (Ti) can also be added to stabilise the materials when operating temperatures are in the critical range of 450°C – 850°C.

The carbon content for standard grades is kept very low, at less than 0,08% carbon (C). The 'L' grades are even lower in carbon at less than 0,03% C. When welding is required on plate material, 'L' grades are recommended in order to prevent sensitization or weld decay in corrosive conditions. The welding of thin gauge sheet materials may not require the use of these 'L' grades.
Characteristics are:

- Non magnetic.
- Cannot be hardened by heat treatment.
- May be hardened by 'cold work' (i.e. rolling, deep drawing, hammering, etc.).

Typical uses are in chemical equipment, process engineering plant, medical equipment, food preparation equipment, and cryogenic plants.

Grades 309 and 310 are used when the operating temperature is in the range of 950°C - 1100°C (chromium content is increased to 24% and nickel varies from 14% - 22%).



Duplex Stainless Steels

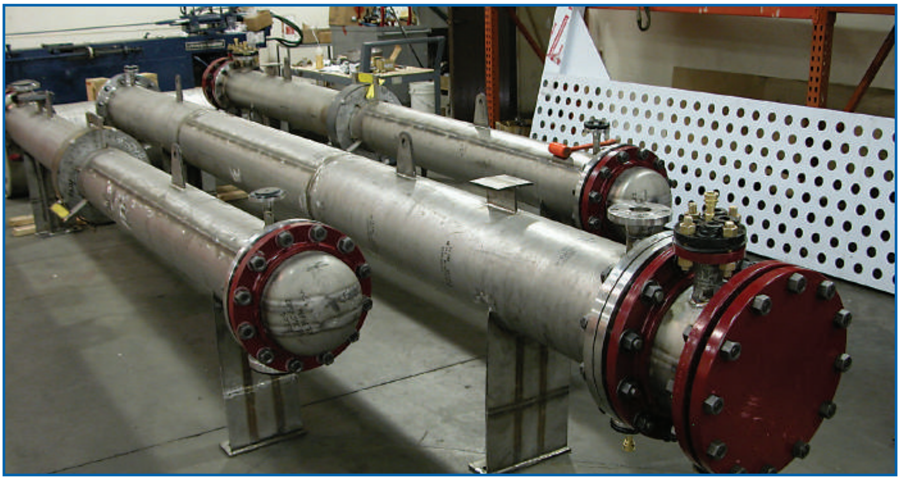
Common grades include:
- 2225
- 2209 LDX.
- Common material – 2205.

This grade of stainless steel is becoming a ever more popular group of stainless steels. They have a mixed grain structure of nearly equal amounts of austenite and ferrite. Chromium content ranges from 21% - 25%, nickel from 5% - 7%, approximately 3% molybdenum and up to 0.17% nitrogen (N). These materials have excellent corrosion resistance, particularly to pitting, crevice and stress corrosion cracking (SCC).They are mostly used in salt water applications with pressure and temperature components.

Special requirements for the welding of duplex stainless steel

It is essential to achieve a correct austenite-ferrite phase balance in the weld deposit and heat affected zone, In order to gain the benefits of resistance to pitting corrosion and stress corrosion cracking. Too low heat inputs tend to increase the ferrite phase too much. Autogenous welding, i.e. welding without the addition of filler metal, or high base metal dilution results in unacceptable high ferrite content in the weld metal.

In order to obtain the correct microstructure and corrosion resistance, welding consumables typically contain nitrogen and higher amounts of nickel. Care should then be taken to use the correct heat input, correct procedure testing, including ferrite measurement is recommended. Restrictions on maximum interpass temperatures and heat input are necessary to avoid second phase precipitates, with these interpass temperatures normally being limited to 150°C.This should be performed using a digital temperature gun.



Martensitic Stainless Steels

Common grades include :

- 410
- 420
- 431.

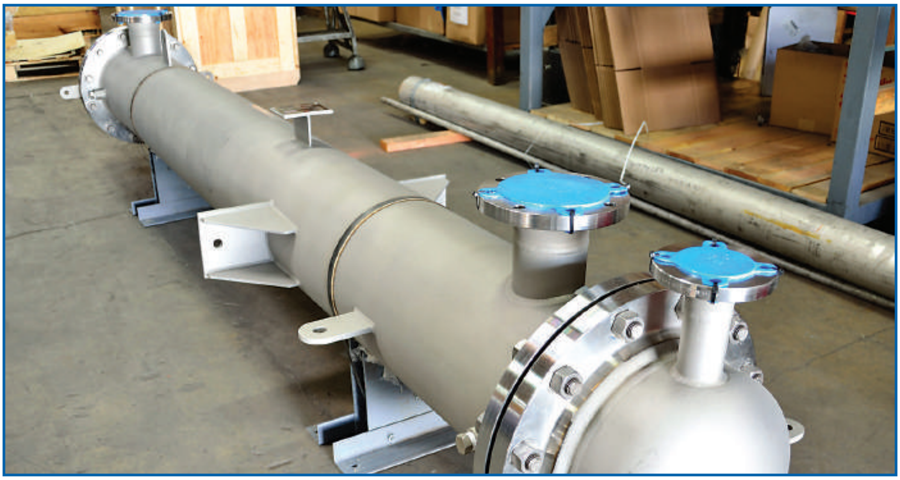
These were the first stainless steels to be produced and are plain chromium stainless steels with high carbon content (0,15% - 1,2%). Due to these relatively high carbon levels, they can be heat treated to obtain high strength and hardness whilst maintaining corrosion resistance.

Special requirements for the welding of Martensitic Stainless Steels:

Due to the difficulty in welding this grade of stainless steel, it requires precise control of pre-heating, interpass temperatures and post-weld heat treatment in order to avoid cracking or enlarged heat affected zones. This material should not be welded without prequalifying the procedure and strict adherence thereof.

The Typical applications for this material are:

- Knife blades
- Shafts
- Nozzles
- Springs and castings.



Welding Processes

Prior to welding, four essential steps must be taken:

- Identify the material, either by the markings on the plate, of by material certificates.
- Select a compatible filler material for the joint to be welded.
- Select a welding process based on the qualified procedure.
- Material characteristics should be taken into account before selecting the welding process.

Selecting a Welding Process

The following factors should be carefully considered in selecting the welding process:

- Quality requirements
- Availability of skilled and qualified personnel
- Consumable availability
- Material thickness
- Welding position
- Welding location – workshop or on-site.
- Productivity considerations - deposition rates
- Equipment availability

Description	Common Abbreviation
Manual Metal Arc Welding	MMA/SMAW
Tungsten Inert Gas Welding	TIG/GTAW
Metal Active Gas Welding	MAG/GMAW
Pulsed/Synergic MAG	
Cold Metal Transfer	Pulsed MAG/ GMAW/CMT
Flux Cored Arc Welding	FCAW
Surface Tension Transfer	GMAW/STT
Submerged Arc Welding	SAW
Plasma Arc Welding	PAW
Micro Plasma Arc Welding	-
Electron Beam Welding	EBW
Laser Welding	LBW
Laser Cutting	LBC
Resistance, Spot Welding	RSW
Resistance, Seam Welding	RSEW
Stud Welding	SW
Friction Stir Welding	FRW
Silver Brazing and Soldering	-
Plasma-Arc Cutting	PAC

The Most Common Arc Welding Processes

The Most Common Arc Welding Processes

Manual Metal Arc Welding (MMA) or Shielded Metal Arc Welding (SMAW)

An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. Both the workpiece and the electrode melts forming the weld pool that cools to form a joint. As the weld is deposited, the flux coating of the electrode melts, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.

Equipment Required

DC rectifiers or inverter technology with electrode the electrode connected to positive (DCEP) give best results with low spatter and low heat input. This is most important in respect of material discoloration and chemical changes in the material. (For further details refer to "Precautions".)

Inverter-type machines are available in 380 V and 220 V supply. These give great advantages in size and weight, with far better welding characteristics.

SMAW/MMA Process Advantages

- The equipment is simple and easy to adjust.
- Electrodes are available from 2,0mm diameter upwards.
- Best results are obtained in the flat or down-hand position, but all positional welding is possible.
- Welding electrodes are available for the full range of stainless steels and alloys.
- Once slag is removed, post-weld cleaning is relatively easy.
- This welding process is ideal for site welding and is ideally suited to confined or difficult to reach spaces.
- Process skills are relatively easy to acquire.
- Quality of the as welded deposit can be of the highest standard.

SMAW/MMA Process Disadvantages

- Can be prone to spatter and accidental are strikes.
- Slow welding speeds – low deposition rates.
- Not suitable for thin sheet metal.
- A range of electrode diameters my need to be kept in stock.
- Baking and drying of electrodes may be necessary to ensure good quality welds, and this must be done in accordance with the manufacturer's recommendations.
- Positional, e.g. vertical, horizontal and overhead, welding is more difficult.
- Electrodes tend to overheat, which reduces the effectiveness of the flux coating.
- Slag entrapment from flux coated electrodes may create problems.
- Interpass cleaning is essential to avoid slag entrapment during multi runs.

Consumables for SMAW/MMA Welding

Proper care of electrodes is essential. Electrodes must not be left lying around exposed to the environment as the flux can get damaged or damp, producing a defective joint. Correct storage in a dry, warm cabinet or holding oven is recommended. When issued out-of-stores, they should go directly to the welder's hot-box to avoid exposure to moisture in the atmosphere particularly in areas of high humidity. Bad habits, such as bending the electrodes and excessive amperage will damage the flux coating, again affecting the quality of the weld.

Welding electrodes can be manufactured in three different ways:

- The core wire generally matches the base material.
- The core wire is a type 304L and the other elements, such as Ni, Dr and Mo are added to the flux.

For this reason one must never strip the flux off an electrode and use it as a TIG rod or as a part for a machine, thinking that one has a matching stainless steel electrode.

The American Welding Society (AWS) has five categories of usability designation for stainless steel electrodes. They are:

- EXXXL-15 (e.g. E308L-15) – a basic lime-coated electrode for use with DC positive only. These are preferred for higher quality work where radiography may be stipulated, high impact properties or repairs on castings.
- EXXXL-16 – a rutile coated electrode which can be used on AC or DC.
- EXXXL-17 AC/DC – used for fillet welds with flat to concave bead shape.
- EXXXL-25 – basic synthetic for down-hand welding using DC positive.
- EXXXL-26 – a rutile basic synthetic for down-hand welding using AC or DC.

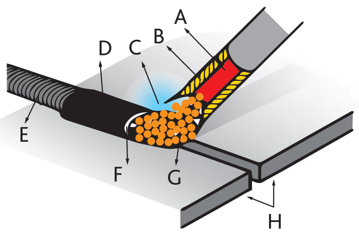
To calculate the heat input, the following formula may be used:

$$\frac{\text{AMPS x VOLTS x 60}}{\text{Travel speed in mm per minute x 1000}} = \text{kJ/mm}$$

Care must be taken to ensure the heat input used during welding will produce a joint having the required mechanical properties. If in doubt, consult an expert. However, values of 0,6 – 1,5kJ/mm are common.

Schematic Representation of Metal Arc Welding

Schematic Representation of Metal Arc Welding



A - Core Wire
B - Flux Covering
C - Shield Gas
D - Solidified Slag
E - Weld Metal
F - Weld Pool
G - Metal Droplets covered in molten slag
H - Parent Metal

Tungsten Inert Gas (TIG) Welding or Gas Tungsten Arc Welding (GTAW)

In the Tungsten Inert Gas (TIG) process, an arc is struck between a non-consumable tungsten electrode and the workpiece. The addition of Filler material is done by hand and is added to the molten pool created by the arc. Inert gas is supplied to protect the weld pool and tungsten electrode from oxidization by the atmosphere. The inert gases used are argon and helium, or mixtures of these, as well as the possibility of small additions of hydrogen (austenitic steel only). It should be noted that pure helium as a shielding gas creates difficulties in arc initiation. For this reason mixtures of argon with the addition of helium are recommended in the ranges of 20-40% helium with the balance of argon. Ideal gas flow rates range between 8-10 LPM.

Power is usually supplied from a DC welding machine, with the torch connected to the negative polarity. This means that one-third of the energy is in the tungsten electrode and two-thirds in the material. This prevents the electrode from burning away and provides the base material with enough heat to form the weld pool. Recent developments in the inverter technology have now superseded the original welding equipment.

A TIG welding system can be as simple as a power pack and torch assembly with a suitable shielding gas supply. If the welding machine has no high frequency facility, the welder would need to 'scratch start' the arc. The risks involved with the 'scratch start' systems are electrode contamination and 'scratch marking' of the base material. The gas flow is regulated either from a valve on the torch body or from the regulator on the gas cylinder. Pre- and post-gas flow is essential to protect the weld and the tungsten electrode from oxidization before and after the welding operation.

Other facilities, such as high frequency start, gas solenoid pre- and post-gas flow are standard features in GTAW AC/DC designed power sources. Remote foot or hand amperage control is generally offered as optional equipment.

More sophisticated machines have a pulsed facility to give high and low background pulses of power to allow fine weld pool control on thin materials, pipe work and critical applications.

TIG Process Advantages

- This process is suitable for material gauges from 0,8mm – 5mm, giving welds of high quality.
- In certain cases autogenous welding, i.e. without filler wire added, can be used to your advantage on thin material for corners, edges and lap welds. Autogenous welding should not be used on duplex materials as this material requires re alloying of the weld weldment with the appropriate filler wire.
- TIG welding is used extensively for root runs on pipe joints, giving excellent control in all positions. This process may

also be used for tacking parts and plates prior to welding with other processes.
- No flux removal is necessary.
- Suitable for automatic and manual methods.

TIG Process Disadvantages

- The TIG process requires a high level of welder skill.
- High heat input levels can produce unacceptable distortion. Copper backing bars and/or greater numbers of tack welds at close spacing may be required.
- The arc must be protected from draughts as the shielding gas can be disturbed. This makes the TIG process less suited to outdoor use.
- Slower and therefore less economical than other processes.
- Needs backing or purging gas to protect the root particularly on pipe welding.
- High quality joint fit up is required

Consumables for TIG Welding

Two consumables are used. These are the filler rod and shielding gas. In addition, other items may need periodic replacement, e.g. tungsten electrodes, collets, ceramics, etc. Ceramic nozzles are available in diameters ranging from 6mm to 15mm. The ceramic will restrict the area of gas shielding and the weld bead width should therefore, always be smaller than the ceramic diameter. Gas lenses are the preferred method of distributing the shielding gas through the ceramic nozzle

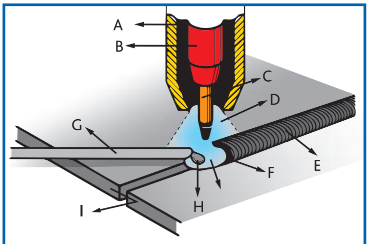
TIG filler rods are produced to be compatible with the parent material. Do not use off-cuts from sheets. Always ensure that the rods are clean and kept in a container. Rods are available in sizes from 1mm – 3,2mm diameter and should be segregated in their respective boxes.

Thoriated tungsten electrodes are available in sizes from 1,0mm – 6.4mm, to optimize current carrying capacity.

Care should be taken in the tip preparation as this can influence the width and depth of penetration. It is recommended that dedicated tungsten sharpening tool is used or if not available, that a dedicated grinding wheel be isolated for tungsten sharpening only. The electrode should be sharpened from the point to the shaft and not in a rotational manner.

Shielding gas is usually argon, which is available in gas or liquid form. Gas purity should be 99,995%, although 99,999% is preferred to avoid welding defects due to impurities. Other gases mixed with argon (for special applications) are helium (up to 40%) and hydrogen (up to 5%). Backing or purging gas, is also required for thin sheet, pipe and platework where welding is done from one side only. For purging applications, inert gases such as argon and nitrogen (austenitic and duplex steels) or a mixture thereof are used. In some cases, small additions of hydrogen may also be used. Hydrogen should not be present when welding the ferritic, martensitic, duplex or 3CR12 grades of stainless steel. Care must be taken when using nitrogen rich purging gases to avoid its dissociation in the welding arc which can result in other harmful weld metal effects. Flow rates of 5-8LPM are commonly used for purging applications. Flux cored TIG wires are available, as well backing tapes, which can negate the need for purging gas, but the use of such materials must be proven for the application.

Schematic Representation of TIG Welding



Metal Active Gas (MAG) Welding or Gas Metal Arc Welding (GMAW)

During the MAG/GMAW welding process, an arc is struck between the parent metal and a electrode. In this process, the electrode is consumed and forms a molten pool into which the electrode melted and deposited. The entire weld area is protected from the atmosphere by a shielding gas consisting of high amount of argon (98%) and low amounts of C02 (2%). This process is suitable for welding material from 1,5mm thickness and upwards in all positions.

Standard MAG welding allows for a number of modes of metal transfer, which is dependent on volts, amps and shielding gas. The most common modes of transfers are:

Dip Transfer or short circuiting arc, i.e. low voltage, low amperage, is very suitable for 2mm – 3mm sheet. A danger of lack of fusion always exists with this particular mode due to lower parameters.

Spray transfer – high voltage & amperage are used and is only suitable for material from 4 mm upwards.

The **Pulsed MAG** process fills the gap between dip and spray modes of metal transfer. This is done by pulsing a base current (low amp/voltage) many a times a second allowing more accurate control of the droplet. This will give advantages such as:

- Reduced heat input.
- Minimal spatter.
- Thinner gauge material can be welded.
- Improved control of weld dimensions and profiles.
- Positional welding capability.
- Reduces the potential for defects such as porosity and lack of fusion.

A shielding gas is necessary, and in this case argon with 2% CO2 is preferred for spray transfer. Special gas mixtures which can include helium, are available for thicker gauge materials which can reduce the need to preheat. The use of this gas can increase penetration and welding speeds or produce a cleaner finish with less spatter levels. As shielding gas technology is a specialist subject, it is always better to consult the gas supplier in these cases. Normal gas flow rates are around 18 LPM.

MAG Welding Advantages

- Continuous wire is feed from a spool as this is a semi-automatic process. Manual MAG welding will thus have fewer stop/starts when compared with the MMA and TIG processes.
- Welding speeds are faster than MMA or TIG and no flux removal is required.
- A single diameter wire can cover a wide range of base material thicknesses. Common wire diameters are 0,8mm, 0,9mm, 1,0mm and 1,2mm.
- The process can be mechanized for longitudinal seam and circumferential welds.
- Very low consumable wastage with 97% recovery.
- Suitable for automatic and manual methods.

MAG Welding Disadvantages

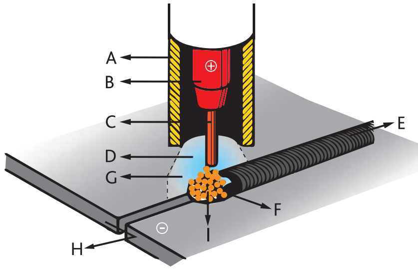
- Cannot be used in drafty of windy conditions without special equipment.
- Positional work requires a greater degree of skill.
- Using the dip transfer mode can produce lack of fusion type defects.
- Precautions need to be taken when depositing root beads, using the spray transfer mode.

Consumables for MAG Welding

- Welding wire supplied in spool form.
- Shielding gas.
- Contact tips, gas nozzle
- Wire feeding liners.

15kg spools or 250kg drums of wire are available in diameters from 0,8mm – 1,6mm. Care must be taken to ensure that the wire is not contaminated with dust, dirt, oil or moisture. Normal workshop consumable store rules apply.

Schematic Representation of MAG Welding



A - Gas Cup
B - Contact Tip
C - Consumable Electrode Filler Wire
D - Shield gas
E - Finished weld
F - Weld pool
G - Arc
H - Parent metal
I - Metal droplet

Flux Cored Arc Welding

Stainless steel gas assisted flux cored wires are available from 0,9mm diameter upwards. These provide excellent current density at relative low currents with better fusion and deeper penetration when compared with MAG welding. The thin layer of slag enables positional welding at high deposit rates, whilst also controlling the solidifying bead shape. Argon with 15 – 25% CO_2 or 100% CO_2 gas mixtures are commonly recommended by the wire manufacturer. Prior to any welding taking place, the wire manufacture recommendations on shielding gases should be strictly followed.

Plasma-Arc Welding (PAW)

Use of the Plasma Welding Process on Stainless Steel

The plasma welding process is used mainly for automated welding applications in the petro-chemical and pharmaceutical industries.

Other applications include the fabrication of storage tanks, railroad tank cars, tanker trucks and seagoing tank containers; production of thermal and nuclear power station plant; manufacture of tubing from plate; off site manufacture of pipe-work systems, etc.

All these applications benefit from the range of qualities offered by the plasma process:

- Reliability and performance.
- Very suitable for welds with access from one side only.
- Little distortion.
- Choice between autogenous welding or addition of cold filler wire.
- Very suitable for mechanised welding.
- Excellent quality welds, which can stand up to most rigorous inspection.
- Finishing operations are reduced and in many cases eliminated.

Plasma Welding Equipment

A plasma welding installation consists of the following main components:

- Plasma power source 25 A – 500 A or similar and pulse current.
- Plasma control unit with PLC and display.
- Wire feed unit.
- Arc height adjustment.
- Plasma welding torch.
- Water cooling device.

A very important part of the installation is the arc height control, which automatically regulates the distance between the weld and torch nozzle through the arc (arc voltage). A constant distance between weld metal and torch is of the utmost importance in achieving a high quality weld.

Plasma-TIG Welding

The 'plasma-TIG' welding process has been developed to improve on the performance of each of the two individual processes, especially in the following applications:

- Longitudinal welding of pipes.
- Butt joining of flat plate in a supporting jig.

- Fabrication of tanks, vessels and containers.

A plasma –TIG welding installation comprises two welding torches:

- A plasma welding torch.
- A TIG welding torch.

Each is connected to a power source. A wire feed unit may be added to complete the system.

The combined process finds most applications in welding thicknesses between 3 mm and 8 mm, edge to edge without bevels. Compared to the plasma welding process it offers the following advantages:

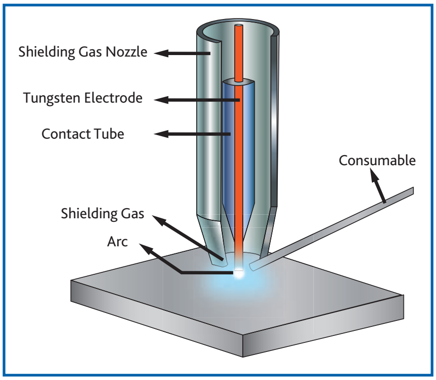
- Improved weld appearance.
- Greater flexibility in preparation for welding.
- Approximately 25% faster welding speed.
- Improved metallurgical quality of the welds.

In most applications, the penetration is achieved by the plasma torch ('keyhole' welding); the TIG torch and associated cold wire feed unit then produce a smooth, convex weld bead. Stainless steels thicker than 8 mm can be welded provided that they are prepared with a bevel having a 5 mm edge. One or more supplementary TIG filling passes may then be necessary.

Each of the plasma and TIG torches may be use independently. For example, the TIG torch can be used on its own to weld plate up to 2,5mm thick.

The arc voltage is regulated to maintain a constant distance between the welding torches and the weld joint, guaranteeing high quality and consistent results. Arc voltage regulation is essential for welding on a boom and where the weld length is 3m or more, even in an installation where the edges to be welded are clamped.

Schematic Representation of Plasma TIG Welding

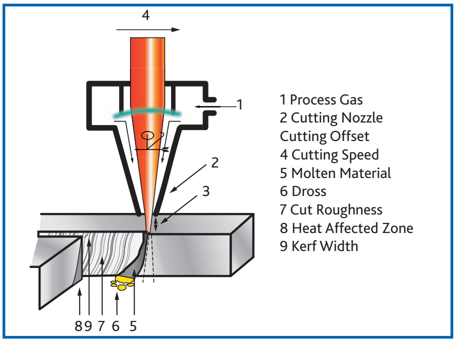


Common Cutting Processes

Plasma-Arc Cutting (PAC)

A plasma arc (a mixture of neutral atoms, free electrons and positive ions) is produced by ionizing a suitable gas or mixture of gases. The plasma torch and the workpiece are changed to opposite polarities, causing a plasma arc to be formed between them. The constricted arc reaches temperatures of up to 25 000°C and the plasma ejects molten metal as a high velocity narrow stream.

Smooth sided cuts can be produced in stainless steel up to 125mm thick. The heat of the plasma arc however results in the formation of a heat affected zone (HAZ) and some distortion of the cut material. Due to possible carbide precipitation on the HAZ that may lead to corrosion problems, the cut edges can be machined to remove the affected region. Plasma arc cuts (kerf width) can be very wide (e.g. 8mm) and the cut edges, on thick material, tend to be slightly sloping.



Cut qualities have however been improved due to more advanced technology and equipment.

In some instances cut qualities of above 10mm thick material are claimed to be approaching that of laser cutting, but at a fraction of the cost.

Laser Cutting

Although laser energy has been used for quite some time, recent improvements in beam quality has extended the capability of lasers, to that of fast high quality precision cutting up to 12mm thick stainless steel. In South Africa numerous high speed laser cutting facilities are now operational. These high speeds are attained via high powered (8Kw) laser systems which generate temperatures beam temperatures in excess of 35 000°C.

A laser beam is a high energy heat source that can be focused to a very small spot, thus achieving extremely high power densities.

Laser cutting has the advantages of very high speeds, narrow kerf widths, high quality cut edges, low heat inputs and minimal workpiece distortion. The process can cut any material and can easily deal with stainless steels. It can only be automated and thus integrated into a programme controlled system for optimal use.

The disadvantages of laser cutting versus plasma cutting lie in the thickness limitation however with the development of higher powered Laser systems these limitations will soon be overcome.

Metal Precautions

If the base material selected for the service conditions and the selected welding process are feasible, then the following should also be considered:

Contamination

The importance of avoiding contamination in welding cannot be over stressed. Hydrocarbons(Oil, dirt, grease) and workshop dust in or near the weld zone can become sources of carbon. Stainless steels have very low carbon levels and increasing the amount of carbon, by way of such contamination, in the molten weld pool can cause weld sensitisation.

Contamination from paint, wax, marking pens, rubber tread marks from shoes and tyres, oil from overhead cranes, dirty gloves and exhaust fumes must be avoided at all cost. In order to avoid pitfalls a systematic approach to good workshop practices must be taken as per the SASSDA Good Workshop Practice DVD.

Correct handling and storage of stainless steel is most important.

- Contamination with carbon steels must be prevented.
- Plate racks, grabs and rollers, work benches, forklifts, and bending devices must be cleaned and protected before use i.e. brown paper, clean wood etc. If mechanical guillotines are used to cut the plates the blades must be wiped down with acetone. This is to prevent iron contamination from these sources which can initiate a site for corrosion.
- The grinding of carbon steels in the vicinity of stainless steels must be avoided at all costs.
- Damage to the protective chromium oxide layer, such as by scraping and scratching when removing from plate racks, must be prevented.
- Mild steel lugs and cleats cannot be welded directly to stainless steel. Either clad the required area by welding, or attach pads of stainless steel and then fix attachments.
- Grinding discs which have been used on mild steel must not be used on stainless steel. Specific grinding discs recommended for use of stainless steels are available from most suppliers.

To ensure proper cleanliness of the weld zone it should be wipe down with a clean rag, dampened with acetone and finally brushed with a clean stainless steel wire brush.

Stainless Steel Brush and Acetone

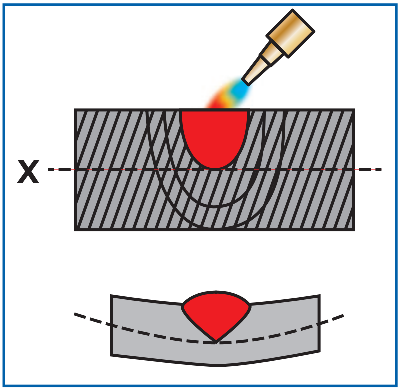
Distortion

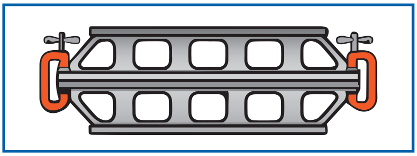
Austenitic grades can create distortion issues. This is due to the heat input created during the welding process which is not easily dissipated and remains close to the heat affect zone (HAZ). This heated area has a high expansion rate, which results in distortion. The following points are recommended to help reduce the problem:

- Use the minimum heat input (KJL/mm) for the section thickness (weld sizes and dimensions are important).
- When butt welding plate from 4mm to 20mm using manual methods, use two-thirds to one-third joint preparation ratio's. Welding on the deeper side first to ensure the penetration is past the midway point will minimize distortion.

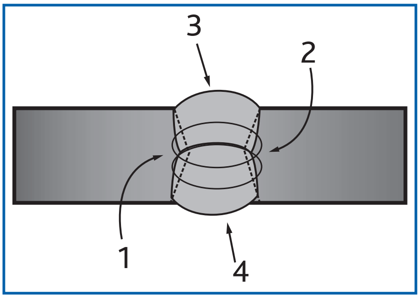
Controlling Distortion

Distortion is a natural tendency in all weldments which is caused by the non-uniformed shrinkage forces created by the welding process.
Here are several practical ways of controlling the shrinkage forces for minimum distortion:
On thick plate >10mm, it may be necessary to

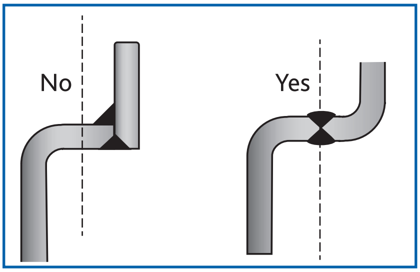




use balance welding techniques, i.e. welding one or two runs then turning the plate over for the next runs. This is repeated until the joint is completed.
Keep to specified gaps and edge preparation

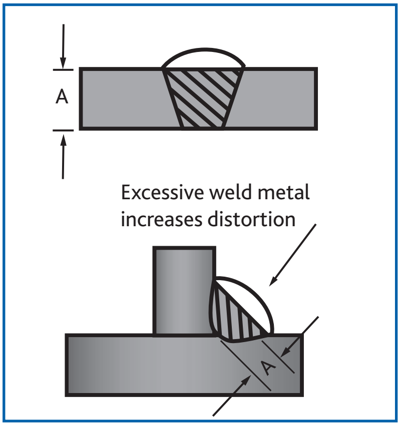


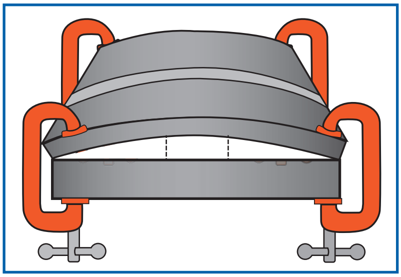
angles. An increase form 60°to 80° can result in approximately 20% extra weld deposit and additional heat input.
The interpass temperature should be around 100°C before starting the next pass.
On thin plate or sheet it may be recommended to use copper chill bars with argon purging wherever possible.
Whenever possible, design the weld along the neutral axis of the component.



When welding circumferentially on vessels, it may be necessary to use internal restraint to reduce shrinkage and distortion. The use of purging equipment is essential to ensure correct weld bead formation and eliminate the possibility of under bead contamination.

Thicker gauges which are to be welded may require tacking at increments of around 20 to 30 times the metal thickness. Peening of these tacks will reduce stress and distortion.

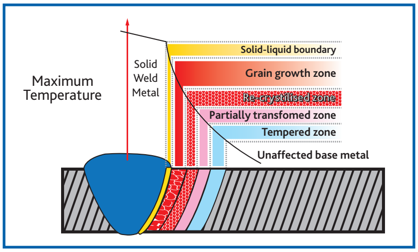




Whenever possible, apply the minimum size fillets with the least amount of excess reinforcement to reduce distortion.

Pre-stressing can employed as a technique to accommodate distortion.

Sensitisation



Also known as excessive chromium carbide precipitation, this condition primarily affects the heat affected zone (HAZ) and is dependent upon the level of carbon present in the material. The length of time that the material stays within the critical temperature range of 450°C – 850°C will also have aggravate the precipitation.

The carbon in the steel combines with chromium to form chromium carbides. These carbides form along the grain boundaries and result in the areas immediately adjacent to the precipitates being low in chromium, i.e. these areas are no longer 'stainless'. Preferential corrosion occurs along these boundaries, resulting in inter-granular corrosion or weld decay.

Prevention

- Low carbon grades (designated by the letter "L" i.e. 304L) of stainless steel and filler material of less than 0,03% carbon should be used.

- Weld zones should be free of contaminants.
- Heat input should be kept low by using low amperage and stringer beads, i.e. no weaving. For this reason a qualified welding procedure (W.P.S) and Procedure qualification record (P.Q.R) must be onhand for easy reference.
- The interpass temperature should be less than 100°C before starting the next run measured by electronic methods
- Stabilised grades of stainless steel which are readily available today can alleviate the problem, i.e. 316 Ti, 321 and 347, if the product application is operating in the temperatures ranging from 450°C – 850°.

In these steels the addition of Titanium (Ti) and Niobium (Nb) combine with the carbon in the grain boundries thus minimizing the possibility of sensitisation or intergranular corrosion. Filler materials for welding these grades are stabilized with Niobium as Titanium is burnt off in the arc.

Hot Cracking

When the weld pool starts to cool down and compounds which have a low melting point such as sulphur and phosphorous are present, these solidify last and form a thin, weak layer between the grain boundaries. Cracking can occur if adequate tensile stresses are present during solidification. To prevent this type of cracking, both the base metals and filler materials should have low levels of impurity.

Fully austenitic weld deposits tend to be prone to centerline cracking. Welds containing sufficient amounts of ferrite overcome this problem and it is common for an austenitic weld deposit to contain between 4% and 12% ferrite.

Fully austenitic weld metal such as type 310 stainless steel is welded with a joint design and welding parameters that will ensure an upwards direction of solidification, i.e. a very convex weld bead geometry must be obtained to prevent cracking.

Large groove angle joint designs promote shallow and wide bead geometries thus should be avoided. Generally, low welding current combined with slow travel speeds promote convexity of the weld bead.

Weld end craters are traditionally concave and are therefore most susceptible to hot cracking if not filled up. This type of cracking is easily corrected by increasing the dwell time at the end of the weld.

Galvanic Corrosion

When two different metals are in contact in an electrolyte (usually a liquid), an electric circuit is set up and current will flow. As a result, one metal will become the anode, the other the cathode. The anode will gradually corrode away, particle by particle. The rate of corrosion will depend on the surface area of the two parts; the bigger the cathode area in relation to the anode, the faster this will happen. When joining two dissimilar materials, it is important to keep this in mind as the weld metal itself could be affected.

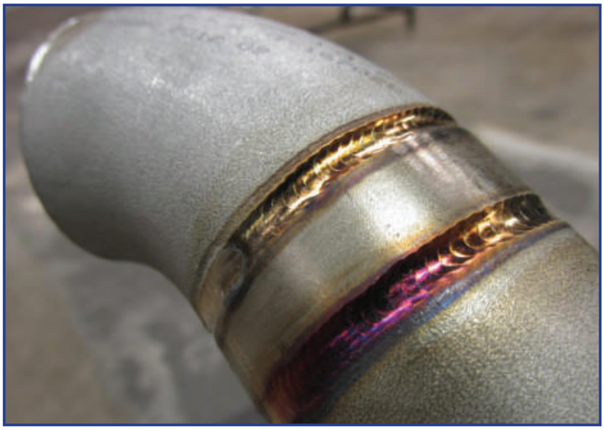
Other examples are arc strikes and spatter which tend to form a very small anode surrounded by a huge cathode. Rapid corrosion can start, which can cause failure in a piece of equipment in a very short time.

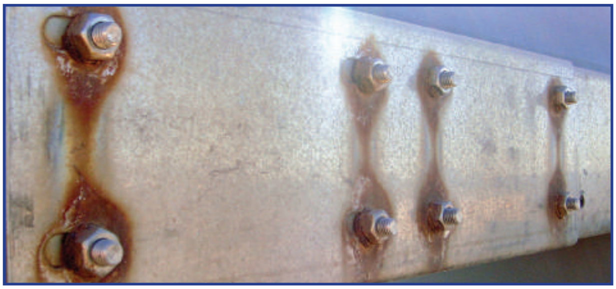
Surfaces damaged by handling, fabrication, cutting and welding must be pickled and passivated.

Thermal Oxides

What makes stainless steel special is the chromium oxide layer formed on the surface. This is called the passive layer and gives the steel its 'stainless' properties. With the heat of welding, this passive layer is burned, which accounts for the many different colours seen in the weld zone.

Thermal, or burned, oxides prevent oxygen reaching the chromium to form a new oxide layer, so it is most important to remove the burnt oxides caused by welding. If this is not





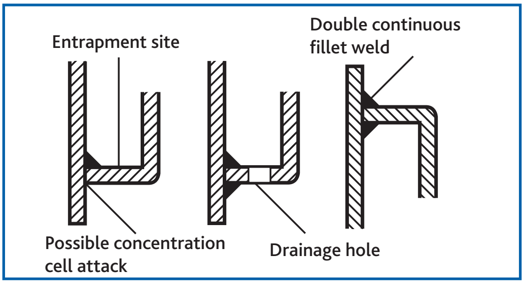
done, the hydrogenous oxide layer, which is responsible for making a stainless steel corrosion resistant, will not be able to form and the affected area will corrode. This unwanted thermal oxide layer can be removed in two ways:

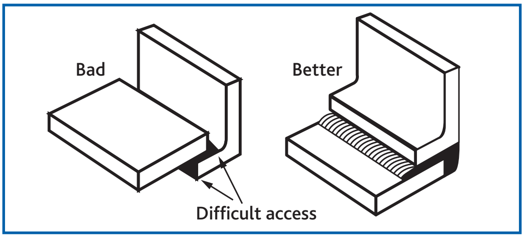
- Mechanically, by polishing or by using stainless steel wire brushes.

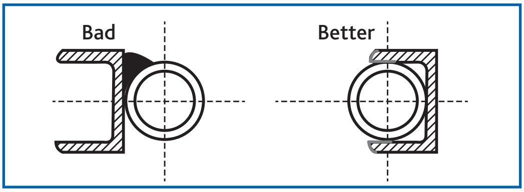
- Chemically, by removing the unwanted oxide layer (pickling). The corrosion resistance in the pickled region may then be restored by passivation which brings it back to its original condition. Pickling and passivation will provide a uniformed protective layer which is aesthetically appealing.

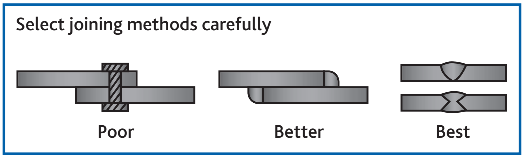
Chemicals for this process may be bought already prepared as pastes or solutions, and are made specifically for each grade of stainless steel. Follow the instructions very carefully and use in a well ventilated place. Plenty of water must be used both to neutralise the acids and to thoroughly rinse the workspace after treatment. Contractors who specialise in this area are available, and may treat large components on site.

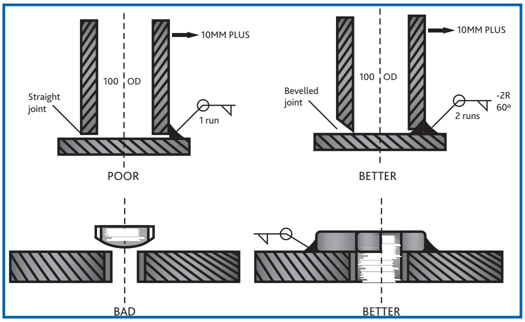
The welding of pipes present a problem when no access is possible to the interior surfaces. It is essential therefore, to purge the inside of the pipe with argon, nitrogen or mixtures with hydrogen to prevent the production of thermal oxides. Care must be taken when selecting purging gas mixtures to ensure no other harmful effects will result. Efficient purging is also dependent upon purge flow rates and pre-welding purge times. In such cases, contact the gas supplier for expert advice.





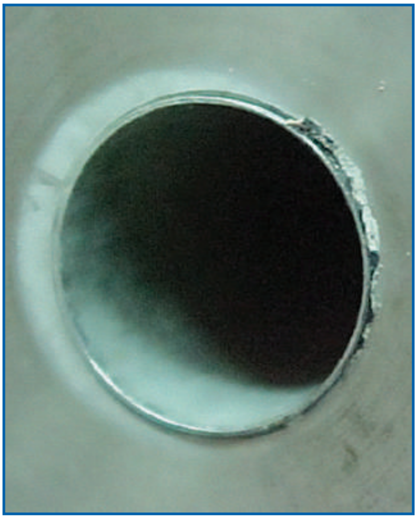






Crevice Corrosion

Poorly formed butt joints which include a backing strips should be avoided at all costs. If these cannot be helped, then it is necessary to seal all around the attachment or fitting, using a continuous weld, to prevent crevices which will cut off oxygen to the passive layer and start corrosion of the material. Spatter will also produce a crevice situation and it must be removed and the area repaired by polishing, buffing and if necessary, pickling and passivating.



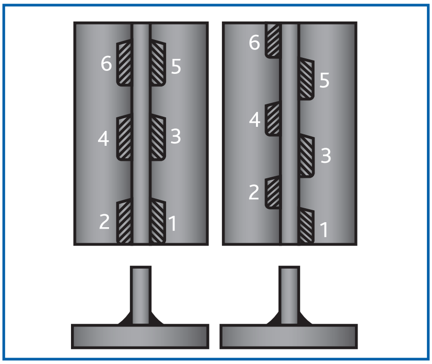
Good Welding Practice

Good Welding Practice

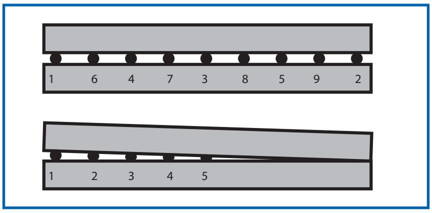
Good welding depends on good welding practice. Some important points to note are:

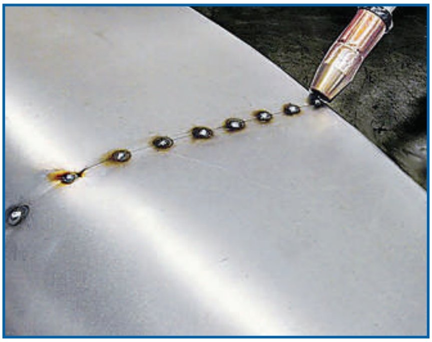
- Ensure proper cleanliness of the weld zone.
- Weld preparation surface must be smooth and free from tears, cracks and nicks.
- Work must be positioned for flat downhand welding whenever possible.
- Arc strikes outside the weld joint are not acceptable. Use striker pads.
- Crater cracks at the end of a weld run must be avoided. Use a small circular movement or back-stepping over the crater.
- Avoid weaving. A stringer bead technique is preferred.
- Gas purging is one of the easiest methods for preventing oxidation on the penetration side of single sided welds.
- When depositing multi-pass runs the interpass temperature should not exceed 100°C.
- Select the correct type of filler material.
- Before tack welding, ensure that the joint geometry is correct, e.g. fit up, root gap & face preparation.
- Interpass cleaning must be undertaken with a stainless steel wire brush only.

Tack Welds Should be Sequenced as Shown

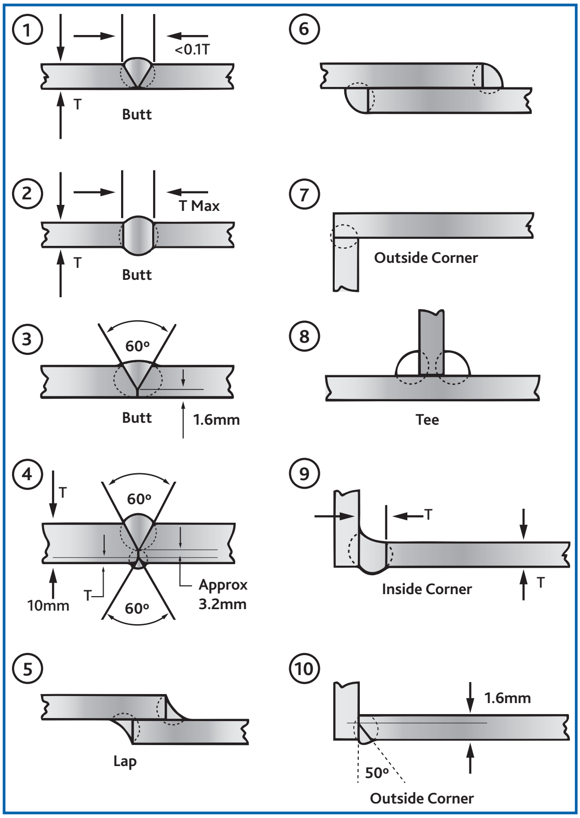


The figures on the diagram below show the correct sequence of tack welding. Those on the bottom show tack welding from one end only. The result is that the plate edges close up.



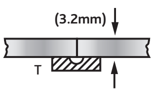
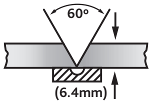
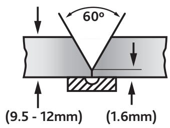


Typical Joint Designs For TIG Welding



Weld Guide Tables - GMAW / MIG

Gas Metal Arc Welding (Semi-automatic)
General welding condition for spray arc transfer
AISI 300 series stainless steels.
Gas - Argon + oxygen.
Gas flow 17l/min

			
Plate thickness (mm)	3.2	6.4	9.5 - 12
Electrode size (mm)	1.2	1.2	1.6
Passes	1	2	2
Current DCEP	225	275	300
Wire feed speed (m/min)	7	10	6.0
Arc speed (m/min)	0.48 - 0.53	0.38	0.15
Electrode required (kg/100m)	7	26	80

Weld Repair of Castings

Weld Repair of Castings

It is essential to know the chemical analysis of the casting to be welded. Ferritic and martensitic materials require great care if welded with a matching type filler material. However, an alternative choice would be to use an austenitic filler material.

Once a defect is located, either by visual or other NDT methods, complete removal is necessary by grinding or arc-air gouging. If gouging is used, back-grinding of the affected area to sound, clean material and to an additional depth of 2mm -3mm, is necessary.

Do not remove more material than necessary and ensure proper access to the bottom of the groove to allow for good fusion. Weld preparation should have an acceptable angle when multi-pass runs are required.

Prior to commencing the weld repair, it may be necessary to check that the defect has been completely removed by examination of the excavated area, using appropriate NDT methods ie dye penetrating spray.

All welding precautions must be taken and strictly adhered to for the particular type of stainless steel casting being repaired.

Dependant on the thickness of the material, pre and post weld heat treatment may be required. When determining the preheat requirements, the schaffer diagram can provide suitable guidelines.

The repaired area must be finally checked, using a suitable NDT method, thus ensuring that the repair has been successful.

Weld Quality, Standards and Codes

Weld Quality, Standards and Codes

In the ISO9000 series of quality standards, welding is regarded as a special process and inspection alone cannot verify that quality requirements have been met. ISO3834 (EN729) is a comprehensive process management system which addresses quality in welding by controlling all aspects of the operation. When ISO3834 is not applied, the requirement of EN1011 parts 1 and 3 should at least be adhered to.

Various application codes/standards exist for design purposes and they cover specific applications such as pressure vessels, pipework and structural fabrication. An application code/ standard also specifies the welding standard/code to be used for welding procedure specifications (WPS), qualification of procedures and welders, aswell as quality acceptance criteria:

When an application code/standard does not specify quality acceptance, ISO5817 (EN25817) is recommended. It offers a choice of 3 levels of acceptance criteria.

The requirement for qualification (approval) of welding procedures is determined by the relevant application standard. EN288 Part 3 and ASME IX require qualification tests for high quality work such as pressure vessels, pressure piping and any applications where consequences of failure require high integrity welded joints. In situations where the weld integrity is less demanding, procedures may be qualified by previous welding experience (EN 288 part 6), a standard welding procedure (EN 288 part 7) or pre-qualification (AWS D1.6) where no specific weld tests are required. Some non-critical applications will not require any WPS qualification and a preliminary WPS (EN 288 part 2) will be sufficient.

Application	Application Code/ Standard	Welding Standard	
		WPS and Qualification	Welder Qualification
Pressure vessels	PD 5500 ASME VIII	EN 288 ASME IX	EN 287 ASME IX
Process pipework	BS 4677 ASME B31.1 ASME B31.3	EN 288 ASME IX ASME IX	EN 287 ASME IX ASME IX
Structural/General	EN 101	EN 288	EN 287
Fabrication	AWS D1.6	AWS D1.6	AWS D1.6

Pickling and Passivation

Pickling and Passivation

The corrosion resistance of stainless steel is produced by an extremely thin but continuous and stable chromium oxide film on the surface of the material. This is known as the passive film.

Damage to this film by means of scraping, gouging fly-off from grinding, carbon steel contamination, arc strikes, spatter and welding can result in local corrosion taking place and a reduction in the life of the components or fabrication.

In particular, weld spatter creates a tiny weld where the molten slug of metal touches and adheres to the surface. The protective film is penetrated and tiny crevices are created where the film is damaged. Heat tint, as several investigations have shown, also weakens the protective film beneath it.

The method used to repair this damage to the passive film and restore it to its original condition is cleaning, pickling and passivating.

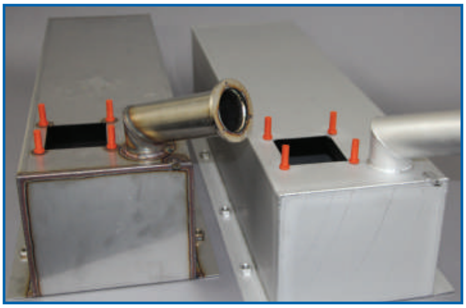
Pickling of stainless steels should be carried out using formulations based on nitric (HNO3) and hydrofluoric (HF) acid. Formulations based on hydrochloric (HCl) acid are not recommended. The formulation must be generously applied to weld areas by brush, cloth, spray or dipping. The formulation should not be allowed to dry, as significant staining of the stainless steel can result. The use of thixotropic pastes is recommended to ensure that the pickling formulation remains in contact with the steel surface for the required period without drying out. Intermittent scrubbing with a stainless steel wire or fibre bristle brush can assist in removal of the discoloration. The temperature of the pickling formulation should not exceed 30°C.

The manufacturer's directions concerning application procedure must be strictly adhered to.

Thorough washing with copious quantities of clean cold water is required after pickling to remove all traces of the acids used.

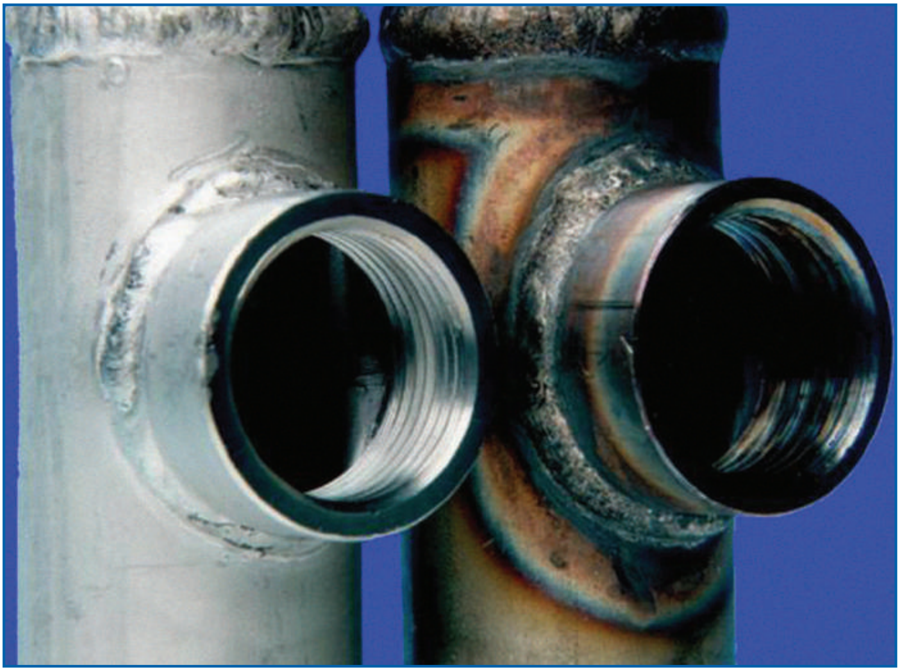
Passivation of Stainless Steels

Nitric acid passivation should be carried out on all mechanically produced surfaces (e.g. machined, ground, blasted, polished), particularly if the component is to be used in aggressive environments.



The acid treatment has the secondary beneficial effect of dissolving any free iron or steel contamination which may have been picked up during handling or fabrication, e.g. from plate clamps, plate rolls, guillotine clamps, flyover from grinding operations on carbon steel.

The quickest and best passivation occurs if used at 65°C for the austenitic (300 series) stainless steels and 50°C for the ferritic and martensitic (400 series) plain chromium stainless steels. Contact time is generally of the order of 30 minutes.



NOTE: Pickling and passivating is carried out with acid mixtures which can be extremely harmful if swallowed of allowed to come into contact with the skin. Suitable safety precautions must be taken to prevent this, e.g. protective face masks, rubber gloves, etc., along with approved, and available, first aid procedures.

Electrolytic Methods

As a result of the inherent dangers associated with the chemical methods of restoring the passive layer, alternative techniques have been developed. A number of proprietary methods are available.

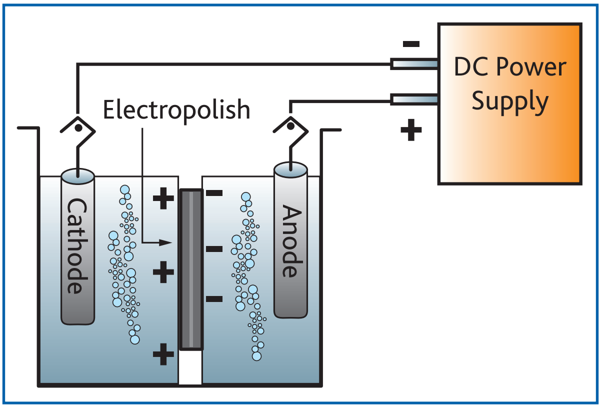
One such method is electrolytic etching. The basic principles of this technique require the application of an electric current across the affected area by means of a suitable electrical circuit, electrode and electrolytic fluid. The apparatus sets up an electrical discharge between the electrode and the affected area which etches the surface leaving a new passive layer underneath. These methods have been tried and are quite successful. Electrolytic fluids are not toxic or harmful and their use increases the safety factor.

Testing for Cleanliness

Several methods of evaluating cleanliness after fabrication are described as ASTM A380-13. Careful consideration of this standard is strongly recommended.

The 'water-break' test is used to determine whether organic contamination, such as oil, has been removed from the surface. Water is also useful in detecting iron contamination – rust streaks and spots will form on wetted surfaces over a period of several hours if contamination is present.

The copper sulphate and ferroxyl tests are much more sensitive than the water test, and are specified when the surface must be entirely free of iron. Special considerations apply when testing equipment intended for use with food, beverages or other products for human consumption. The ferroxyl is effective and easy to use, although the solution does not have a long shelf life.



Contact

For assistance or advice on any aspect of this guide, contact:

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Website: www.sassda.co.za

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