How to Weld & Maintain Stainless Steel

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By Leif Andersen, TE Andersen Consulting.

Is Stainless Steel different from Steel, except that it does not rust?

Absolutely, stainless Steel is very different. **In order to weld it correctly you have to understand the difference.**

Poor heat conductivity (40 % less than steel).

The heat does not spread out in the surrounding material but build up locally and tend to overheat the material. This is caused by Chromium and Nickel being the main alloying elements. These metals are not good conductors.

Higher coefficient of expansion (40 % higher).

Expansion followed by contraction will give distortion and tension as a result. This makes stainless steel constructions buckle and bend and become out of shape after welding.

Structural changes following welding.

Most Stainless Steels have an Austenitic structure (the way the atoms organize themselves). This structure can be distorted depending on heat input during welding.

Sensitive to certain corrosion phenomena.

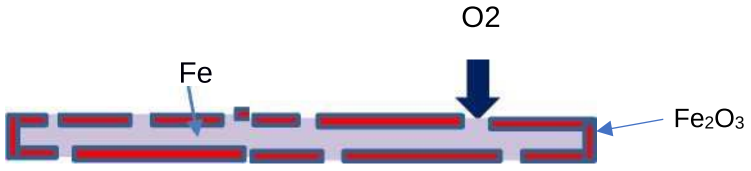
Given the right circumstances, Stainless Steel can rust like any other metallic material.

Based on the above, first rule of the game is:
Keep heat input as low as possible.

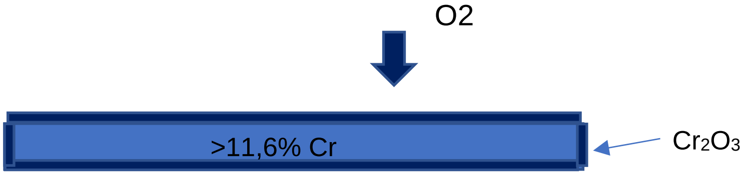
1) If you can avoid welding, do not weld.

What makes stainless steel rust proof?

When the surface of normal steel is exposed to oxygen, it usually forms iron (Ferrum) oxide (Fe_2O_3) which has the well-known red rust color. Iron oxide doesn't form a continuous layer on the steel because the oxide molecule has a larger volume than the underlying iron atoms, and eventually spalls off leaving fresh steel exposed which then starts a deleterious rusting cycle.



In Stainless, this will turn out differently. If the Chromium content is over a certain value, (> 11,6%) the oxygen will go in contact with the Chromium and form Chrome oxide (Cr_2O_3). The Chrome oxide is a thin and transparent layer, but very dense and will seal the surface so oxygen cannot penetrate any further.



2) Never paint or coat Stainless Steel.

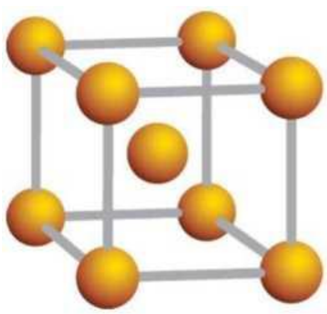
It is important that oxygen get to the surface. There are however exceptions where coating of the stainless is necessary because of the environment.

Stainless steel can be divided into several groups (AISI= American Iron & Steel Institute).

FERRITIC	AISI 409,430,434,439
MARTENSITIC	AISI 403,410,420&440A, B, C
AUSTENITIC	AISI 200 and 300
SUPER AUSTENITIC	(254 SMO)
DUPLEX	Austenitic/Ferritic
CLAD STEEL	Compound steel/Sandwich steel

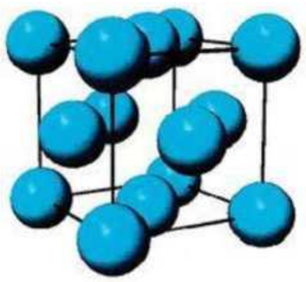
FERRITIC stainless steel is used in applications where products require resistance to corrosion at elevated temperatures rather than strength. They are magnetic and non-hardening. Applications: Kitchenware and other utilities. Poor welding ability.

MARTENSITIC stainless steels used in applications where resistance to abrasion in high temperature applications are important. They are magnetic and can be hardened by heat treatment. Applications: Ball bearings, pump shafts, gas turbine components etc. Poor welding ability
Ferritic and Martensitic steels are defined by a Body-Centered Cubic (BCC) grain structure. In other words, the crystal structure of such steels is comprised of a cubic atom cell with an atom in the center. This grain structure is typical of alpha iron and is what gives ferritic and martensitic steels their magnetic properties.



Body-Centered Cubic (BCC) grain structure.

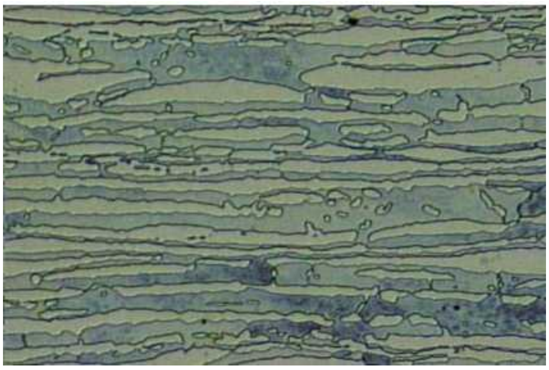
AUSTENITIC stainless steels have the highest tonnage of weld able stainless steel produced. These are the chromium nickel steel of the AISI 200 and 300 series in which chromium usually exceeds 17% and nickel with few exceptions exceeds 7%. They also have the highest corrosion resistance of all the stainless steels. Most materials for chemical carriers are selected from this group of materials. They have a Face-Centered Cubic (FCC) grain structure and are therefore Austenitic and nonmagnetic.



Face-Centered Cubic (FCC) grain structure

SUPER AUSTENITIC stainless steel such as Allegheny Technologies' alloy AL-6XN and Outokumpu's alloy 254 SMO, possess great resistance to chloride pitting and crevice corrosion because of their high molybdenum content (>6%) and nitrogen additions. They are high alloy Austenitic stainless steels developed for use in seawater and other aggressive chloride-bearing media (Saltwater handling, Flue gas desulfurization scrubbers, Flue-gas cleaning, Desalination, Heat exchangers onboard).

DUPLEX stainless steel has a mixed microstructure of austenite and ferrite, the aim usually being to produce a 50/50 mix, although in commercial alloys the ratio may be 40/60. Duplex stainless steels have roughly twice the strength compared to austenitic stainless steels and improved resistance to localized corrosion, particularly pitting, crevice corrosion and stress corrosion cracking. They are characterized by high chromium (19-32%) and molybdenum (up to 5%) and lower nickel contents than austenitic stainless steels.



Microstructure of base metal of the duplex stainless steel, 2205, 250X original magnification. Austenite phases are present as white island in blue sea of ferrite.

CLAD Stainless Steel is a thin layer of Austenitic stainless steel on to a layer of steel. The stainless layer is approximately 2-3mm (5/64-1/8”) in thickness. The stainless furnishes the necessary resistance towards corrosion; abrasion or oxidation and the steel backing material contributes structural strength. The principal cladding techniques include hot rolled bonding, cold rolled bonding and explosion bonding. Hot rolled bonding accounts for more than 90% of the clad plate production worldwide. It is also known as the heat and pressure process. The principle involves preparing the cleaned surfaces of the cladding components, heating to the plastic range, then bringing the stainless and backing into contact by either pressing or by rolling.

How to go about welding Stainless Steel:

In the following, we will give attention to welding of Austenitic Stainless steel that is the most likely type of stainless alloy to be welded on-board. We have previously mentioned that the heat during welding of stainless steel can give un-desired consequences. Therefore, we must strive for as low as possible heat input during a welding job.

3) Never pre heat Stainless Steel.

If plates or pipes are moist, it might be necessary to dry the material by light heating to 40-50 °C (104-122°F).

The alloying elements in austenitic stainless steel is as follows:

Cr >11,6% Chromium in order to become corrosion resistance and to increase resistance to oxidation at high temperatures.

Ni >6% Nickel that slightly increases the corrosion resistance and that greatly increases the mechanical properties. It will also swing the structure towards becoming Face-Centered Cubic (FCC) in grain structure (Austenitic). It is important that the weld deposit do not become fully austenitic. Ferrite is better at dissolving impurities such as sulphur, phosphorous, lead and tin. Low ferrite content 0-3% can make welds sensitive to hot cracking.

Hot crack in weld deposit with too low ferrite content.

A consumable with a ferrite content of 3-10% gives high resistance to cracking.

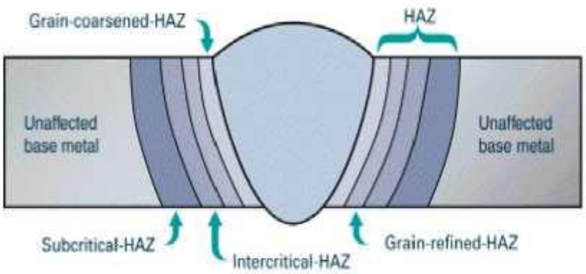
4) Select a welding electrode that as welded produce the sufficient content of ferritic structure (FN: Ferritic number) This indicate the approximate content of ferritic structure in the final deposit.

All weld metal composition

C	Mn	Si	Cr	Ni	Mo	FN
max. 0.030	0.5 - 1.2	max. 0.9	17.0 - 19.0	11.0 - 13.0	2.5 - 3.0	3-10

5) Select a welding electrode with less than 0,04% of carbon (C).

This is very important because in the temperature range from 430-870°C (750-1550°F) the carbon and the chromium bond together in the stainless steel and form carbides. These carbides situate themselves at the stainless steel grain boundaries, and the grain boundaries become deficient of chromium. The Heat Affected Zone (HAZ) will be the likely place for this to happened.



With lower chromium concentrations at the grain boundaries, the chromium oxide protective layer can become discontinuous and rusting becomes possible. (Intercrystalin corrosion)

If only Cr and Ni are added, we refer to the stainless material as AISI 304 (American Iron & Steel Institute) If the carbone content of the electrode is below 0,04% its referred to as AISI 304 L (Low carbone). Without the L the carbone content in an ordinary stainless steel electrode can be as high as 0,08%.

Make sure the electrode classification has the letter L.

AWS AS. 4	EN 1600	ISO 3681
E 316 L-17	E 19 12 3 LR 12	E 19.12.3 LR

If the alloying elements in austenitic stainless steel also contain Molybdenum 2- 3 % (Mo) we refer to the stainless as Acid resistant and AISI 316. Molybdenum will increase the resistance to pitting corrosion.

C	Mn	Si	Cr	Ni	Mo	FN
max.0.03	0.5-1.2	max. 0.9	17.0-19.0	11.0- 13.0	2.5 - 3.0	3-10

6) For an AISI 316L acid resistant steel make sure to select an electrode with same classification. If pitting corrosion is a problem an AISI 317L electrode with higher Mo content might be recommended.

Regarding Super austenitic stainless steels:

The steel is characterized by the following properties:

- Excellent resistance to pitting and crevice corrosion, PRE = ≥42.5*
- High resistance to general corrosion
- High resistance to stress corrosion cracking
- Higher strength than conventional austenitic stainless steels
- Good weldability

*The Pitting Resistance Equivalent Number (PREN) is a measure of the relative pitting corrosion resistance of a stainless steel grade in a chloride- containing environment. The higher the PREN value, the more corrosion resistant the grade will be. It is defined for austenitic grades by PREN = %Cr + 3.3 x %Mo + 16 x %N

Chemical composition of Super austenitic stainless steels:

Cr 20%, Ni 18%, Mo 6.1%, N 0.2%, Cu 0.7%, C <0.02%

The weldability of 254 SMO is good. Welding should be undertaken without preheating, and if correctly performed there will be no need for any subsequent heat treatment. Suitable methods of fusion welding are manual metal-arc welding with covered electrodes and gas-shielded arc welding, mainly by means of the TIG and MIG methods.

Since the material is intended for use under severe corrosive conditions, welding must be carried out with care and followed by thorough cleaning to ensure that the weld metal and the heat-affected zone maintain the best possible corrosion properties.

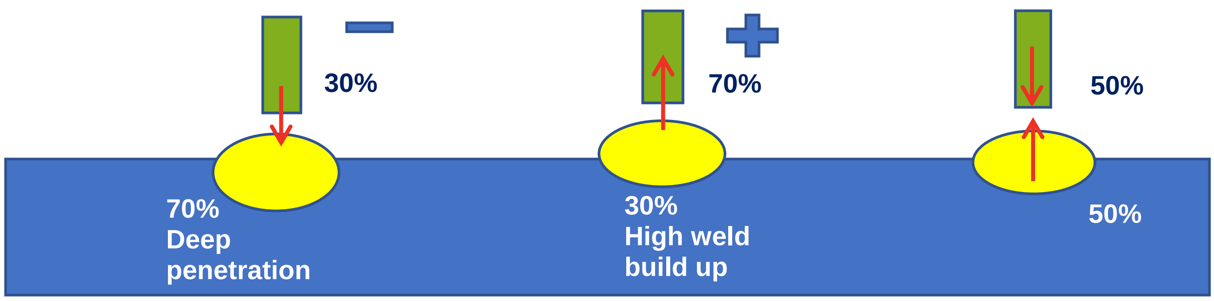
The welding of fully austenitic steels usually entails a risk of hot-cracking in the weld metal, particularly if the weldment is under constraint. However, since 254 SMO has a very high degree of purity, the risk of this type of cracking is greatly reduced. Backing bars or similar devices of copper alloys must not be used since copper penetration into the grain boundaries in stainless steel can lead to cracking.

In common with all austenitic stainless steels, 254 SMO have low thermal conductivity and high thermal expansion. For this reason, welding should be carefully planned in advance so that distortion of the welded joint can be minimized. If, despite these precautions, it is believed that residual stresses may impair the function of the weldment, it is recommended that the entire structure be solution annealed.

7) Use only dry electrodes. Re-dry if necessary, to 350°C (662°F) for 2 hours. Electrodes can be re- dried up to 3 times.

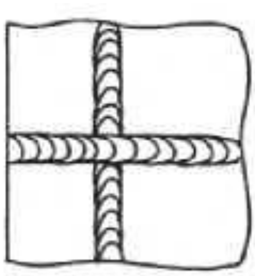
8) Use DC + polarity to electrode holder

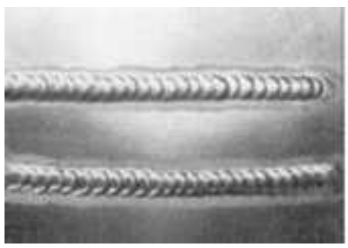
DC Straight Polarity DC Reverse Polarity AC



The arc temperature is 7000 °C (12632°F). It is important that the heat input to the base material is as little as possible. Electrons move from – to +. If we connect the electrode holder with the electrode to - polarity, the electrons bombard the plate and 70% of the heat ends up in the base material. If we reverse the polarity and connect the electrode to + polarity, we will create the opposite effect and have less heat input to the base material. Stainless steel welding using electrodes must therefore always be done connecting the electrode to + polarity.

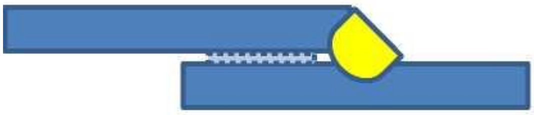
9) Crossed weld joints are undesirable. In general, welds must not be located to close to one another.

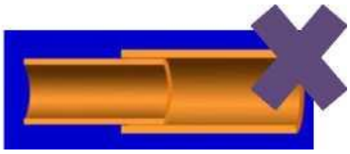




10) Avoid overlap joints.

A galvanic cell can occur within an apparently homogeneous material due to several processes one of which is differential aeration where one area is exposed to more oxygen than another. The area with less oxygen becomes anodic and will corrode. This is referred to as crevice corrosion. Butt joints are the preferred joints for stainless steel. The disadvantage of stainless steel is that in low oxygen environments, such as boil feed, the corrosion resistance is actually reduced. In addition, stress corrosion cracking and pitting can occur when in the presence of chlorine ions. In this way, stainless steel is not recommended in situations where stagnant seawater might exist as it could perforate quicker than mild steel. The chlorine ions are the correct right size to enter the atomic matrix of the metal and their concentration accelerates corrosion by the propagation of cracks. Catastrophic failure can occur.



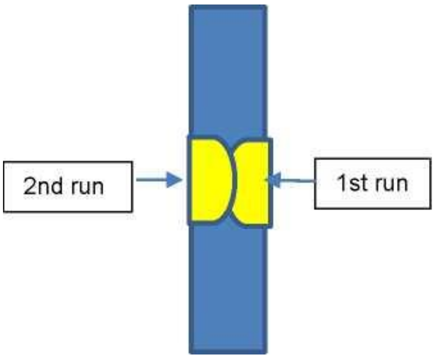


11) Tack weld must be done with short distance between the tacks.

Expansion followed by contraction is much stronger in stainless steel and create tension that will give distortion as a result if tacks are too far apart.

12) Weld side exposed to corrosion as 2nd run.

Side exposed to corrosion media



13) Use stringer beads. Avoid weaving.

Weaving reduces the welding speed and increases the heat input. Only use small weaving motion to avoid convexity of weld profile.

Weaving

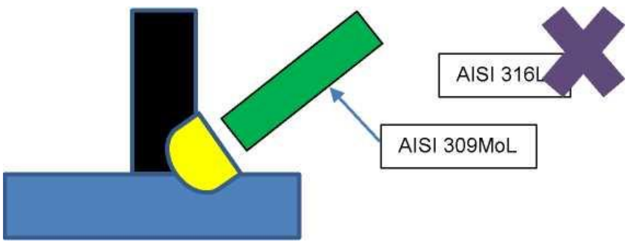
Stringer beads

14) Always use the largest size diameter electrode that the groove can accept (but not at the expense of not getting down into the groove).

Using a large size diameter means that you reduce the heat input in relation to the amount of filler metal deposited. For instant a 4,0 mm (5/32") electrode deposits four times as much weld metal at only two times as much amperage compared to a 2,5 mm (3/32") electrode. Do not use too high amperage. Follow manufacturer's recommendations.

15) Avoid welding stainless steel to mild steel.

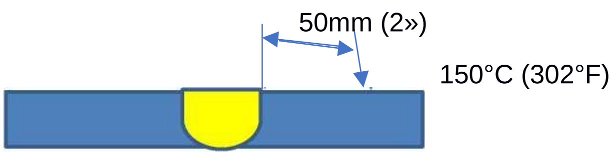
If welded with an ordinary AISI 316L type of electrode the mild steel will dilute down the amount of chromium in the weld deposit to below 11,6%. The result will be that there will not be sufficient chromium to create a chrome oxide layer. It is therefore important to use an over alloyed stainless steel electrode AISI-309MoL with higher content of Chromium and Nickel.



16) Welding Clad steel (Compound steel): Use a combination of E-7018 type basic coated low hydrogen electrodes towards the mild steel. Towards the stainless part use AISI 309MoL type of electrode.

17) Max interpass temperature: AISI 316 L : 150°C (302°F).

The Interpass temperature is the temperature in the stainless steel during welding measured 50mm (2”) from the welding joint.



Do not weld so that the temperature goes above 150°C (302°F). Try to spread the welding, thereby the heat input out by welding in different location. For duplex stainless steel, the interpass temperature can be up to 250°C (482°F).

For Super Austenitic stainless steel (254 SMO) the heat input during welding should not exceed 1.5 kJ/mm, and in multi-pass welding the interpass temperature should not exceed 100°C (210°F). A stringer bead welding technique should be used.

18) Use only Stainless Steel Chipping hammer and Stainless Steel Wire brushes.

Use of mild steel wire brushes and chipping hammers will contaminate the stainless steel surface and trigger rusting. In general, equipment and accessories for stainless steel welding should be kept separate from mild steel equipment.

19) Use only Stainless Steel Grinding, Cutting and Mopping discs.

Iron free (inox) grinding discs is to have less than 0,1 % content of iron, chlorine and sulphur compounds.

20) Use Pickling Gel to remove discoloration and to passivate the surface.

Pickling Gel consists of Hydrofluoric acid, Nitric acid & a Binder. It removes welding oxides, the underlying chromium- depleted layer, micro-slag particles and other contaminants that may cause local corrosion. In this way, oxygen in the air can once again have access to a surface that have the right amount of chromium to create a defensive chrome oxide layer.

21)Check weld repair by the use of Crack Detector Kit.

Stainless steel can develop hair line cracks difficult to detect without the use of a good crack detector kit.

22) Cover tank bottoms so that equipment, tools, footwear do not get in direct contact with the stainless surface. Remove all slag, electrode stubs and coatings after welding.

WELDING CONSUMABLES & PRODUCTS FOR STAINLESS STEEL

Normal recovery AISI 316L stainless steel electrodes:

Lincoln Electric	Esab	Bohler	Wilhelmsen Ships Service	Drew Marine	Kobe steel (Kobelco)
Limarosta 316L Veratarosta 316L (Vertical down)	OK 63.30	FOX EAS 4M-A	Unitor 18/8-321N	Amerarc ST Amerarc STV (Vertical down)	NC-36L

Elga (ITW)	Kjellberg	BOC (Linde)	Philarc	Oerlikon (Air Liquide)	Hyundai
Cromarod B316L	Finox 4430AC Finox 4430 F (vertical down)	Smootharc S316L	Galvastain 316L	Supranox RS 316L	S-316LT.16

Normal recovery AISI 309Mo electrodes:

Lincoln Electric	Esab	Bohler	Wilhelmsen Ships Service	Drew Marine	Kobe steel (Kobelco)
Arosta 309Mo	OK 67.70	FOX 23/12 Mo-A	Unitor 23/14-322N	Amerarc SSMO	NC-39MoL

Elga (ITW)	Kjellberg	BOC (Linde)	Philarc	Oerlikon (Air Liquide)	Hyundai
Cromarod 309MoL	Finox 4459	Smootharc S309MoL	Philstain 309MoL	Supranox 309MoL	S-309L

Normal recovery Duplex electrodes:

Lincoln Electric	Esab	Bohler	Wilhelmsen Ships Service	Drew Marine	Kobe steel (Kobelco)
Arosta 4462	OK 67.50	FOX 22/9N	Unitor DUPLEX-325N	Amerarc DP	NC-2209

Elga (ITW)	Kjellberg	BOC (Linde)	Philarc	Oerlikon (Air Liquide)	Hyundai
Cromarod Duplex	Finox 4462 AC	---	Philstain 2209	Supranox E2293N	S-2209.16

Oerlikon have an AISI 317 electrode Supranox 317 with higher Molybdenum content than the standard AISI 316.

SUPER AUSTENITIC Stainless Steel (254 SMO)
Sandvik covered electrode Sanicro 60 are recommended as filler metal. This filler metals are over alloyed in order to compensate for micro segregation of molybdenum and thereby producing a weld with good corrosion resistance. Dilution from parent material into the weld metal should be kept as low as possible to secure good corrosion resistance. Sanicro 60 is also suitable for welding joints between 254 SMO and nickel alloys, other stainless steels or carbon steels.

Maintenance of stainless steel, is that really necessary?

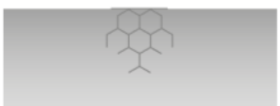
YES. One of the problems with stainless steel is that they are susceptical to rust if they do not receive correct maintenance.

Stainless steel is rust proof because oxygen in the air will combine with the chromium in the stainless and create a thin transparent layer of Chromium oxide. This layer is so dense that the oxygen cannot penetrate any further into the material. If the chrome oxide layer is removed by for example a tool, the oxygen will rush in and renew the layer. For this to take place the chromium content in the stainless material must be above 11.6%

Stainless steel can in some situations start to rust. These are as follows:

GENERAL CORROSION: In acidic or alkaline solutions.

INTERGRANULAR CORROSION: High carbon content + Temp.



PITTING CORROSION: Chloride containing environment (Seawater).

CREVICE CORROSION: Narrow crevices filled with liquid where the oxygen level is very low.

STRESS CORROSION CRACKING: Tensile stress and corrosive environment (chlorides or other halogens) Increasing with salt concentration and temperature.

All the above-mentioned types of corrosion can take place in stainless steel depending on the environment and how we handle and weld stainless steel. Never the less the phenomena we call flash rusting is probably the most common type of stainless steel rusting.

Flash rusting: The reason for this phenomenon is when small steel particles fall or swirl down onto a stainless steel surface. When combined with moisture, they quickly dissolve due to the base character of the steel particles. There is a relatively large potential difference between stainless steel and carbon steel, which is why this reaction occurs extremely quickly. In practical, the term iron particles often used, but what is actually meant is steel particles. During dissolution of the steel particles, iron oxides are created that contaminate the surface of the stainless steel. In addition, oxygen is somewhat prevented from entering the area, because of which the stainless steel surface becomes activated locally. This then leads to contamination corrosion.

Examples include steel particles that are a result of grinding dust and showers of sparks that develop during carbon steel grinding. The mentioned particles are particularly dangerous because they can burn into the stainless steel surface whilst the core of these particles still contain unburnt steel. In addition, the abrasive movements of the carbon steel and stainless steel together can also lead to contamination corrosion in the end. This is way stainless steel needs to be protected from carbon steel.

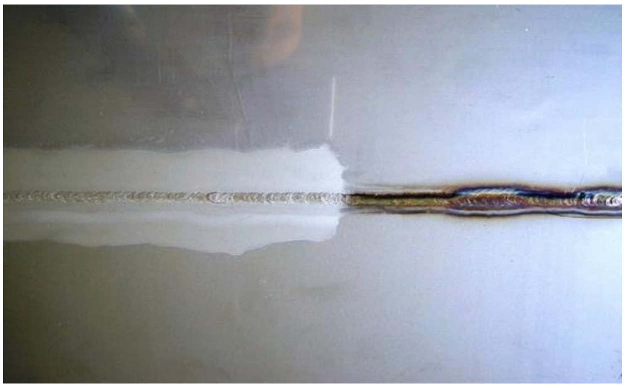
Aerosols Local rust spots can also develop due to aerosols. This primarily happens out at sea and in coastal areas. Aerosols are small droplets of seawater that are carried from the sea surface by the wind and which evaporate during their flight leading to further increase in salt and chloride concentrations. This forms a greater corrosive load for stainless steel than normal seawater. The result is local corrosion that can even develop into pitting corrosion at times.

Therefore: Stainless steel is not maintenance free. If the oxide film on its surface is perforated by steel particles, the film will be unable to recover automatically. Under the oxide film there is always an active metal and as soon as moisture is added this film will start corroding. The passive film must therefore remind intact at all times.

How to maintain Stainless Steel:

Clean stainless steel pipes and plates with regular intervals. Use natural solvent limonene saturated cleaning wipes. This type of wipes is ideal for cleaning stainless surfaces where contamination can severely affect the integrity of the chrome oxide film. Use the smoot side of wipe to clean the surface. If flash rusting has started to develop use the abrasive side of the wipe to remove contamination followed by the smooth side to re wipe the surface to ensure all impurities are removed.

If flash rusting has developed to a larger extent: Use Stainless Steel wire brush. Larger areas consider mop discs for stainless steel that are iron free. This must be followed by acid pickling using pickling gel.



Pickling Gel consist of Hydrofluoric acid, Nitric acid & a Binder. It removes welding oxides, the underlying chromium- depleted layer, micro-slag particles and other contaminants that may cause local corrosion. In this way oxygen in the air can once again have access to a surface that have the right amount of chromium to create a defensive chrome oxide layer.

Application.

Pickling products are hazardous substances that must be handled with care. The pickling area should be ventilated. Users should wear protective gloves and face visor.

1. Pretreat oxides; slag and weld defects mechanically, preferably when the welds are still warm and the weld oxides less hard.
2. Give the area to be pickled time to cool down to below 40°C (104°F) after welding.
3. Organic contaminants such as grease, oil and paint have to be removed.
4. Stir the gel to a smooth consistency and spread a thick layer on to the work piece using a brush.
5. The work piece should be cold when the gel is applied, although the air temperature must not be below + 5°C (41°F). Do not pickle in direct sunlight.
6. The gel should be allowed to remain for at least 50 minutes. For Mo-alloyed steels this time should be extended. If necessary, the gel may be allowed to remain on the work piece over night as there is no risk for corrosion.
7. After appropriate time, rinse off the reminding gel using fresh water. If necessary, brush the weld with a stainless steel wire brush.
8. Pickling residuals and rinse water should be neutralized to pH-7 i.e. with Neutralizing Agent, and then rinsed with water. For the deposit of heavy metals, local water pollution control regulations should be consulted.
9. The bottles must be stored in an upright position with the lid tightly closed. Storing temperature 20°C (68°F). Storage temperature higher than 45°C (113°F) must be avoided since this accelerate the ageing process.

Different pickling gel brands:

Lincoln Electric	Esab	Bohler Avesta Polarit	Wilhelmsen Ships Service	BOC (Linde)	Oerlikon (Air Liquide)
Picklinox gel	Stain Clean pickling gel	Blue One Pickling paste 130	Unitor Pickling gel	Smootharc Stainless steel pickling gel	Picklinox G Restorinox G

For further information on pickling and cleaning of stainless steel go to Avesta Polarit Handbook for pickling and cleaning.