# SELECTION OF SHIELDING GASES FOR STAINLESS STEEL WELDING

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The shielding gas is important not only to the quality of the weld but also to productivity and working environment.

## INTRODUCTION

### The importance of the shielding gases

Optimizing the welding process means considering the whole system that is the choice of filler metal, the shielding gas, the powersource as well as the welding parameters. Optimizing could have a different meaning for different manufacturers depending on demand on corrosion resistance, mechanical properties, surface appearance, productivity, working environment etc.

The choice of shielding gas influences the welding process to a different extent in different welding processes. In figure 1 the features of the shielding gas in GMAW (MIG/MAG).

When welding of stainless steel the weld pool and the hot metal should be shielded from air. This is preferably done with a non-oxidizing gas. However, in GMAW a low percentage of oxygen ($O_2$) or carbon dioxide ($CO_2$) is often needed in the shielding gas to improve in arc stability.

Other gases, such as nitrogen, helium, hydrogen and nitric oxide, is sometimes added to obtain specific properties.

### Arc stability and metal transfer

As mentioned, oxygen or carbon dioxide are added to improve arc stabilfty and reduce spatter formation in GMAW. Typical levels for welding with solid or metal cored wires are 1-2% oxygen or 2-4% carbon dioxide. If the oxygen level is less than 1% or the carbon dioxide level less than 2%, the wetting effect is not sufficient. Higher levels of oxygen and carbon dioxide than 2 and 4% respectively gives excessive oxidation. In some cases, with very high alloyed steels or nickel-base alloys, pure argon is used even for GMAW. These high-alloyed materials are so sensitive to oxygen that normal shielding gases for GMAW of stainless steel will cause too much oxidation of the weld surface.

For welding with flux cored wires (FCAW) a completely different range of shielding gases is used. Most gas shielded flux cored wires have been developed to be used with a shielding gas containing 20-100% carbon dioxide. In FCAW a shielding gas with less than 20% carbon dioxide usually results in less good arc characteristics.

Helium is a non-oxidizing gas like argon and is sometimes used in the shielding gas for welding of stainless steel. In GMAW and spray arc welding, a shielding gas with too high precentage of helium resulta in a less stable arc due to amongst others, forming of larger drops. For short arc welding on the other hand a higher helium content can be benificial. To get the best out argon and helium, a mixture with 30-40% helium, a few percent of an oxidizing gas and the rest argon often is used as an all round gas.

### Loss of alloying elements and carbon pick-up

Both oxygen and carbon dioxide give oxidation losses of alloying elements, mainly manganese (Mn) and silicon (Si), when droplets from the molten filler metal pass through the arc. For corresponding percentage of oxygen

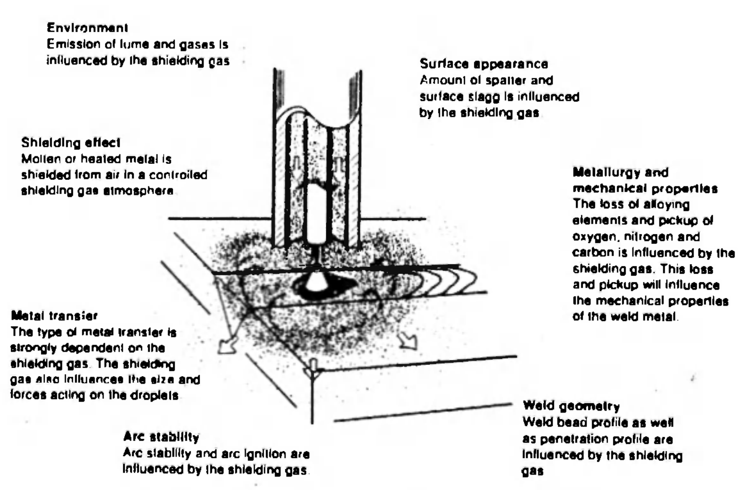


*Fig. 1 The influence of the shielding gas upon GMAW.*

and carbon dioxude, the oxidation loss is higher with oxygen, even if no oxygen or carbon dioxide is present in the shielding gas some losses take place due to vaporization.

Carbon dioxide in the shielding gas can sometimes result in carbon pick-up in the weld metal. If the carbon content is too high, chromium carbides might precipitate in the grain boundaries above a certain temperature. The areas close to the grain boundaries will get a lower chromium content and will therefore be more sensitive to corrosion (grain boundary corrosion). The risk is usually very low when the shielding gas contains less than 3% of carbon dioxide (Figure 2).

In FCAW where much higher levels of carbon dioxide are used, an effective slag system counteracts the carbon pick-up. Therefore the difference in carbon pick-up is marginal between 20 and 100% carbon dioxide when welding with such wires.

## Productivity

The welding speed can sometimes be increased when helium is present in the shielding gas. Helium has a higher heat conductivity than argon and for the same arc length and current the voltage also is higher. This means that the heat input with helium will be higher for the same welding speed or the higher energy can be used to increase the welding speed. In GMAW it is especially in short arc welding that the beneficial effect of helium can be utilized.

Also in other processes, like in GTAW (TIG), high helium contents in the shielding gas produce good welds at high welding speeds. This is especially used for nickel-base alloys and sometimes also for ferritic and duplex stainless steels. Addition of hydrogen in GTAW or plasma welding (PAW) can also be used to in

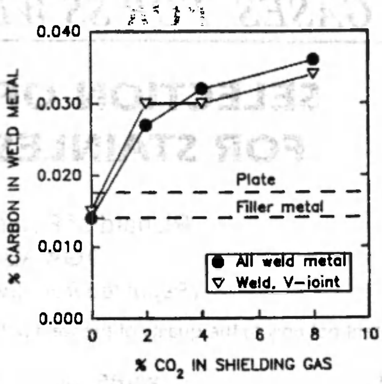


Fig.2. Carbon level in weld metal with different carbon dioxide contents in the shielding gas [6]

crease the welding speed. It should, however, only be used for austenitic stainless steels due to risk of hydrogen embrittlement.

## Weld geometry

When carbon dioxide is used in argon for GMAW, the voltage has to be a little higher than with oxygen. This, in conjuction with a more favourable effect on the surface tension results in a more flat weld with carbon dioxide, especially in short arc welding.

Oxygen and carbon dioxide also change the heat conductivity compared to pure argon and this affects bead geometry and penetration in the base material in a positive way.

As mentioned before, the heat input is increased when helium is used in the shielding gas. At unchanged welding speed, a greater penetration profile can be achieved with helium due to the higher energy and a broader arc.

Hydrogen addition gives a more narrow and more deeper pnetration profile and is used mainly in GTAW and PAW. Hydrogen, which is a reducing gas, reacts with oxygen why less oxides are formed.

A disadvantage with hydrogen is the risk for hydrogen embrittlement. This is especially important when steels with a high percentage of ferrite or martensite are welded. Materials that therefore can be considered as a "risk group" include ferritic, martensitic and possibly duplex stainles steels.

## Corrosion resistance and mechanical strength

Recently there has been much interest in adding nitrogen($N_2$) to the shielding gas in gas shielded arc welding of stainless steel. Nitrogen addition to the shielding gas is used mainly to improve pitting corrosion properties but also to some extent to improve mechanical strength. Pitting resistance at the root side is also increased by using pure nitrogen or nitrogen with 5-10% hydrogen in the root shield.

Nitrogen in austenitic stainless steel plays a role similar to that of carbon in increasing the mechanical strength but without the associated disadvantages related to precipitation of carbides [1],[2].

In high alloyed stainless steels ("Super austenites" and "Super duplex") high contents of chromium, molybdenum and nitrogen results in good resistance to pitting and crevice corrosion. If nickel is used instead of nitrogen, similar corrosion properties can be achieved but there is a tendency to precipitation of intermetallic phases e.g. Sigma Phase [4]. This is a reason to use high nitrogen contents in these materials. Typical levels of nitrogen in nitrogen alloyed stainless steels are 0.1-0.3%.

When welding nitrogen bearing stainless steels, there is a loss of nitrogen in the weld which decreases the pitting corrosion resistance. In GTAW with filler metal and in GMAW this can be compensated for by a proper alloying of the filler metal. In GTAW and PAW of thin material, without filler metal, the loss of nitrogen has to be compensated for in another way. This can be done by using an argon/nitrogen mixture as shielding gas.

Argon-based shielding gases containing nitrogen to give a certain nitrogen level in the weld are used commercially today. Most commonly these shielding gases consist of argon with 2-5% nitrogen. It is however not easy to reach the desired nitrogen level in the weld metal since the amount of nitrogen that goes into solution in the weld pool is strongly dependant of the arc energy and heat input [3],[5]. If nitrogen is going into solution in the weld pool the N2 molecule has to be dissociated, that is split into two free nitrogen atoms. To which degree this is done depends a lot on the energy in the arc.

In GTAW the arc voltage is linear to the stand-off distance. This means that the arc temperature and the dissociation level of nitrogen varies with varied standoff distance [5]. In practice this means that the nitrogen level in a weld, made with manual GTAW, can vary along the weld due to small changes in stand-off distance. Other factors effecting the nitrogen pick-up are current and welding speed.

Since so many parameters influence the nitrogen pick-up it is advisable to use argon/nitrogen mixtures only for mechanized welding where the process is easier to control. To obtain a desired nitrogen level in the surface layer on the root side is easier. It is less sensitive to variations in welding parameters. Suitable gases are pure nitrogen or nitrogen with 5-10% hydrogen.

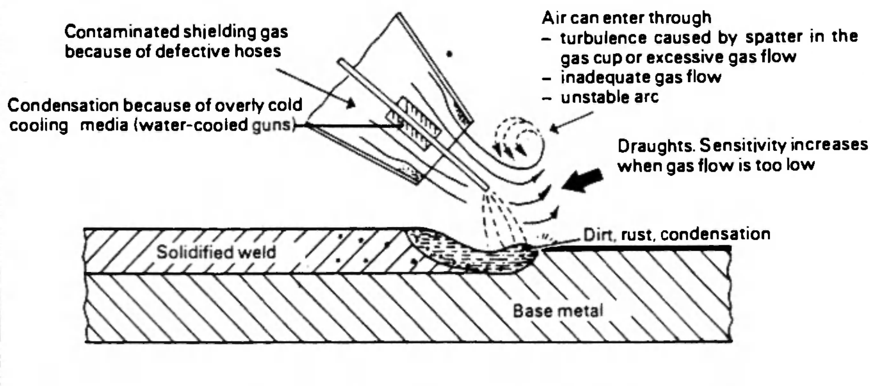


Fig.3. How the shielding gas atmosphere and weld pool can be contaminated in GMAW.

Typical applications where it is beneficial to use argon / nitrogen/ mixtures are GTA welding to thin sheets and the longitudinal seam of thin-walled tubes and pipes, especially in duplex stainless steel.

With nitrogen in the shielding gas the right ratio of austenite and ferrite can be achieved without addition of a special filler metal.

## Root side shielding

In some applications the root side of the weld have to be protected. If not an oxide layer will be formed. The layer of oxide contains chromium which has been taken from the metal immediately beneath this layer. Due to lower chromium content in this zone the corrosion resistance will decrease. A study [7] has shown that for maintenance of corrosion resistance of an standard type of austenitic stainless steel, the oxygen content in the shielding gas should not exceed 25 ppm.

In order to reach such low concentration of oxygen it is necessary to purge the weld thoroughly with root gas before welding begins. Purging of the root side must continue even after welding until the temperature has fallen below 250°C. Beneath that level no oxidation takes place which could deteriorate the corrosion resistance of the steel.

The following gases are normally used for root protection : argon, argon/hydrogen, nitrogen/hydrogen and helium.

Argon is the most common backing gas. The standard quality of argon is normally enough for keeping down the oxygen content The addition of hydrogen to argon provides a reducing gas that countracts oxide formation while giving the root a smoother and more uniform shape.

Nitrogen with 10% hydrogen is also a common root gas and has just as good shielding effect as the other two.

Pure nitrogen is quite unusual as a backing gas for the moment, but an increased use can, however, be seen for welding of duplex stainless steels. The use of nitrogen increases the pitting resistance in the root side of the weld.

Helium has a lower density than air which gives it a raising effect. It can therefore be used to remove trapped air in high positions (table 1).

| Gas | Density (kg/m) at 1Bar 15°C | Density in relation to air |
|---|---|---|
| Air | 1.213 | 1 |
| Nitrogen | 1.170 | 0.96 |
| $N_2$+10% $H_2$ | 1.061 | 0.87 |
| Argon | 1.669 | 1.38 |
| Helium | 0.167 | 0.14 |
| Ar+70% He | 0.620 | 0.51 |
| Ar + 30% He | 1.220 | 1.01 |

Tabel 1. Densities for different root gases.

Argon or helium are recommended for root protection of non austenitic stainless steels. Hydrogen is often avoided due to the risk for hydrogen embrittlement. Nor should gas mixtures containing nitrogen be used. Nitrogen is a strong austenite-former, and in cases where it is desired to maintain the ferritic structure entirely, nitrogen should not be used.

## Contamination to be considered in welding

Gaseous contaminants that can cause problems if present in exesive concentration are oxygen, nitrogen, hydrogen and moisture. Gases like oxygen and hydrogen is often added to the shielding gas in order to improve the stability of the arc or to improve the appearence of the weld. These gas mixture should only be used for welding of materials that are not sensitive to these particualr gas components.

The contaminations originate from different sources. Oxygen, nitrogen and moisture exist in air and can penetrate the gas shield. Moisture is dissociated in the arc into hydrogen and oxygen atoms.

Hydrogen can originate from moisture, e.g.condensation on the surface of filler metal or base metal or from grease and oil.

Figure 3 shows how contamination can enter the shielding gas atmosphere and the weld pool.

Other major contamination sources are, leaking connections and diffusion through hoses.

It is however important to point out that contaminants seldom or never are present in the shielding gas itself.

How sensitive to contamination are the stainless steels then? Contamination of weld metal can cause porosity, embrittlement, and reduction of corrosion resistance of the weld. Both porosity and embrittlement lead to weakening of a weld.

In welding stainless steels a distinction must be made between austenitic, martensitic and ferritic steels as well as combinations of these steels, as they possess different sensitivity to contaminations.

Martensitic and ferrite-martensitic steels are senstitve to hydrogen and moisture contamination because of the risk for hydrogen embrittlement.Other stainless steel types are not as sensitive.

Austenitic stainless steel is in term of porosity fairly insensitive to nitrogen. Up to 5% can be permitted in the shielding gas. Nevertheless nitrogen can have a negative effect on austenitic stainless steels. Nitrogen lowers the level of ferrite (there should be some ferrite in austenite) and thus increases the risk for hot cracking during welding. Ferritic stainless steels possess a greater sensitivity to nitrogen. Since ferrite has a lower capability of dissolving nitrogen in comparison to austenite, the risk for pore formation increase with higher nitrogen levels.

Oxygen primarily effects the corrosion resistance of stainless steel. Oxygen can lead to a brittle layer of oxide forming on the surface of the weld metal during welding. This oxide contains high levels of chromium, and the chromium being absorbed from the underlying steel thus reduces the corrosion resistance of the metal. This oxide should be removed through pickling or by mechanical means.

## Working environment in welding of stainless steels

In welding, air pollutants are generated and take the form of dust, fume and gases. Dust particles fall in close vicinity to the arc because they are comparatively large and heavy.

Welding fume, consists of extremely small particles, usually less than 0.5 micrometer in diameter.

The details connected with stainless weldings are as belows :-

- Chromium, Cr. Trivalent and hexavalent chromium are formed through oxidation. Both forms produce irritation of the mucous memberanes, metal fume fever and they also effect the respiratory passages and the lungs.
- Nickel, Ni, Nickel oxide in welding fume can cause metal fume fever.
- Ozone, $O_3$, Ozone in a colourless, toxic gas and is formed in all arc welding. Ozone affects the mucous memberanes, mainly in the respiratory passages.

  Symptoms of ozone include itching or burning in the throat, coughing, chest pain and wheezing.
- `Hydrogen has also an Ozone reducing effect which however is much smaller than that for nitric oxide. A common shielding gas containing 2% hydrogen results in about two times higher ozone emission than gases with an additon of 275 ppm, nitric oxide.
- Carbon monoxide (CO) is formed when carbon dioxide is split in the arc. Carbon monoxide is a dangerous gas which is odourless and colourless. There is usually no problems with carbon monoxide but measures should be taken to prevent high concentrations when welding in confined spaces with straight carbon dioxide.

## Trends in welding of stainless steels

There has been a change in welding of stainless steels during the last years. More GMAW, both with solid and flux cored wires, is used and the MMA welding is decreasing. GMAW has found its reputation in the stainless industry since both filler metals and shielding gases have been improved to suit welding of different stainless steels.

There is a tendency to an increased use of helium containing shielding gases for GMAW due to the better productivity that can be obtained with these gases.

The most fast-growing group of stainless steels is the duplex grades. They have a growth rate of 30-35% in Europe and development of the weldability of these materials is therefore of great interest both to producers of consumables and users. It is interesting to note that helium addition to the shielding gas is of importance when it comes to welding of duplex stainless steels, A shielding gas with a composition of Ar + 30% He + 1% $O_2$ has been found to be the best gas for GMAW of both duplex and superduplex stainless steel.

The use of nitrogen in the shielding gas in GTAW to improve corrosion properties of welds in duplex stainless steels are probably going to increase in the close future.

## CONCLUSION

Pure argon or argon with addition of 0.03% NO to reduce ozone emmission is recommended for GTAW, in general and for GMAW on nickel based stainless steels.

Argon with 1-2% oxygen gives a stable arc in GMAW and is suitable for most applications with no risk for carbon pick-up in the weld metal.

Argon with 2-4% carbon dioxide gives about the same result in GMAW as argon with oxygen.

Fluidity of the weld pool and weld geometry is usually a little better with carbon dioxide in argon, especially in short arc welding. These gases should not be used for GTAW.

Argon with more than 18% carbon dioxide or pure carbon dioxide is normally used in FCAW of stainless steels. The use should follow recommendations from filler metal manufacturers.

Welding speed or penetration can sometimes be increased when heiium is added to the argon, argon + oxygen or argon + carbon dioxide shielding gas. About 30% Helium is needed to achieve this effect. Helium is used in GMAW as well as GTAW. High content of helium in combination with high current or pulsed GMAW may result in a less stable arc.

Hydrogen addition in the shielding gas (normally about 5%) can be positive for penetration depth and welding speed in GTAW. Hydrogen (normally 5-10%) in the backing gas has a benificial influence on low oxidation at the root side. Care should be taken for materials sensitive to hydrogen cracking when hydrogen is used in the gases.

Nitrogen is used in the shielding gas for GTAW and the root gas in general to improve pitting resistance as well as mechanical properties. When used in the shielding gas it cen be difficult to control the nitrogen absorbtion in the weld metal.

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