ZAŠTITA KORIJENA KOD ZAVARIVANJA NEHRĐAJUĆIH ČELIKA I OSTALIH MATERIJALA

BACK SHIELDING OF STAINLESS STEEL AND OTHER METALS

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Ključne riječi: zaštita korijena, sadržaj zraka, zaštitni plinovi, ostatni sadržaj kisika, vlaga, izvori vlage, dušik, utjecaj na aluminij, utjecaj na ugljični čelik, utjecaj na nehrđajući čelik, utjecaj kod tvrdog lemljenja bakra, crijeva.

Key words: back shielding, contents of the air, shielding gases, residual oxygen, humidity, sources of humidity, nitrogen, effect to aluminium, effects to stainless steel, effects to mild steel, effects to brazed copper, hoses.

Sažetak: Zaštita korijena vrlo je važan dio kod procesa zavarivanja. Kao što koristimo zaštitne plinove da bismo odstranili prisutnost zraka u području zavara, zaštitni se plinovi mogu koristiti i za zaštitu na strani korijena zavara. Djelovanje zaštitnog plina gotovo je isto. Korijen i zona utjecaja topline štiti se od oksidacije, kemijske reakcije s dušikom i prodiranja vlage te na taj način i od djelovanja vodika. Svi su metali osjetljivi prema djelovanju jednog od ili više sastojaka zraka. Iako utjecaj kontakta korijena zavara s atmosferom nije previše intenzivan u usporedbi s gornjim dijelom taline, dolazi do značajnih kemijskih reakcija. Ove reakcije dovode do oksidacije, slabljenja otpornosti koroziji, vodikovih pukotina te do krtosti, dolazi do reakcija s dušikom i mnogo drugih oštećenja. Osim kod zavarivanja nehrđajućih čelika, zaštita korijena ne primjenjuje se u praksi. U članku će se pokazati da ima razloga i smisla primjenjivati zaštitu korijena i kod zavarivanja drugih materijala.

Abstract: Back shielding is a very important part of a welding production. As we use shielding gases to separate the air from the welding area shielding gases can also be used to protect the root side. Some effects are nearly the same. The root and the heat affected area get protected against oxidation the chemical reaction with nitrogen and the dilution of humidity and this way the dilution of hydrogen. All metals are sensitive to one or more components of the air. Even if the contact of the root side to the atmosphere is not as intensive as at the top layer chemical reaction will happen. These reactions lead to oxidation, loss of corrosion resistance, hydrogen cracks, embrittlement by dilution of and reactions with nitrogen and many more damages. Apart from welding stainless steel back shielding is not very popular. This article will show that back shielding makes sense even when welding other metals.

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1. INTRODUCTION

For more than 40 years, root protection and forming have proven their value in welding technology. They permit an increase in weld seam quality and contribute to a reduction of follow-up costs. The focus here is on reworking, pickling costs, the associated transport costs and the not inconsiderable loss of time. With correct forming, weld seams and roots can be produced which need no reworking.

This way back shielding got one of the most important applications when welding stainless steel. It prevents the material and the heat effected zone against oxidation. This is necessary to guaranty the corrosion resistance to the steel. But as stainless steel has problems with oxygen, which is one of the components of the air, other metals also have problems affected by the other components of the air. Aluminium for example is sensitive to humidity, mild steel to humidity and nitrogen, and also when brazing copper oxidation may happen to the material and to the flux. So, also when welding or brazing other materials like aluminium, titanium, magnesium or copper the root side should be protected. Otherwise the welding of gas sensitive materials such as titanium, zirconium, molybdenum or magnesium is not possible without forming.

2. BACK SHIELDING - DEFINITION

Back shielding means flushing the root of the weld and the heat affected zone with inert gases at the same time displacing oxygen, nitrogen and hydrogen witch are components of the atmosphere (DVS-MB 0937). In relation to pipelines and vessels we are talking about forming. In this case, the entire vessel, or pipe gets completely filled with shielding gas. This method is used in the welding processing of gas-sensitive materials such as in high-alloy stainless steels. This way the corrosion resistance of corrosion-resistant materials is guaranteed. Without forming an oxidation of the weld and of the heat affected zone throughout the oxygen containing atmosphere will happen. This process takes place, depending on the sensitivity of the material, even at temperatures down to 250 °C.

Back shielding can’t be substituted from the welding production of components made of high alloy steels or other gas sensitive materials. These way attractive welds of high quality can be produced economically. Also during tack welding back shielding is required because annealing colors or the formation of oxides or nitrides is irreversible.

3. COMPONENTS OF THE AIR AND THEIR INFLUENCE

The influence of the different components of air to different metals witch can be welded or brazed is different. Air consists of:

- Nitrogen 78 %
- Oxygen 21 %
- Argon 1 %
- Humidity

The reaction between these components and the materials can cause nitrides, oxides or combinations.

Further we have hydrogen dissolved of the humidity. If we take a look at our chemistry book we can find a fundamental reaction:

$$2H_2O \leftrightarrow 2H_2 + O_2$$

This reaction will happen at temperatures above 2000 °C. In presence of steel for example the dissolving of hydrogen is reduced to 650 °C.

$$H_2O + Me \leftrightarrow H_2 + MeO$$

Now we have molecular hydrogen witch can be solved in the microstructure. Welding other metals we will have other reactions. This article will be restricted to:
- Stainless Steel
- Mild Steel
- Aluminium
- Magnesium
- Titan
- Copper.

3.1 Oxygen and stainless steel

Stainless steel is sensitive to oxygen. The material and the alloying elements from the root side of the seam and the heat affected zone form oxide layers. These oxides may consist of iron, chromium, nickel, titan, niobium etc.

Oxygen is available directly from the air. Additional oxygen is available by dissolving humidity.

$$H_2O + Fe \leftrightarrow H_2 + FeO$$

The oxide layer has different thicknesses and due to this different so called annealing colours. This area has no longer the same corrosion resistance like the ground material.

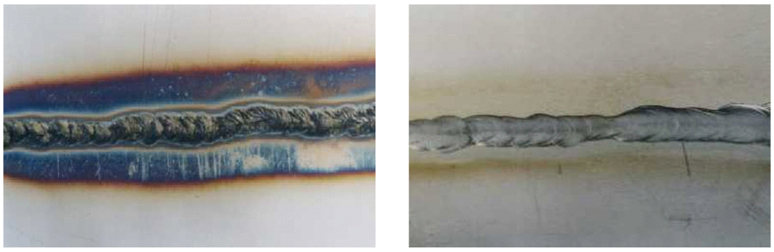


Figure 1: Rroot with and without back shielding

Such oxidized seams and heat affected zones must be cleaned. This means brushing, grinding, sand blasting or etching. These procedures are expensive and need a lot of time. Another solution is back shielding. It helps to save money and time.

3.2 Humidity and oxygen in aluminium

Aluminium is sensitive to oxygen and humidity. In contact with oxygen it forms oxides and it has a high solubility for hydrogen. Oxygen is available directly from the air. Another supplier for hydrogen and oxygen is humidity. The solubility of liquid aluminium for hydrogen is very high but when it gets solid it has a spontaneous decrease of the solubility.

As the time for hydrogen is to short to come out of the liquid aluminium it leads to the formation of pores.

Aluminium oxides have some special disadvantages. At first Al_2O_3 causes embeddings on the surface of the root side witch have the effect like a notch. Further these oxides have a lower density as the liquid melt pool. They rise up through the melt pool to reach the top layer. On their way to the top the oxides get embedded into the seam.

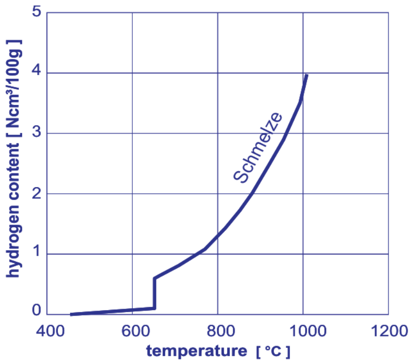


Figure 2: Dilution of hydrogen in aluminium

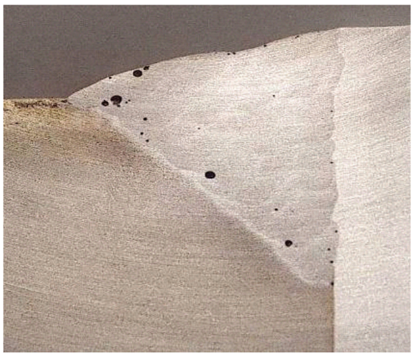


Figure 3: Pores caused by hydrogen

If we compare the roots with and without back shielding we can clearly see the result of the oxidation.

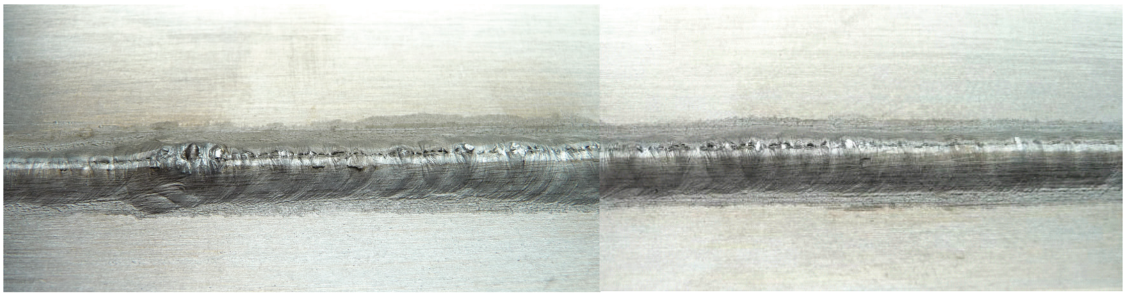


Figure 4: Overview of a root without back shielding

Figure 5: Extension of a part of the root

Although the sheets and the welding wire have been grinded directly before welding a high grade of oxidation is to be seen. These oxides lead to kerfs in the middle of the root. Also the x-ray picture shows these little kerfs.

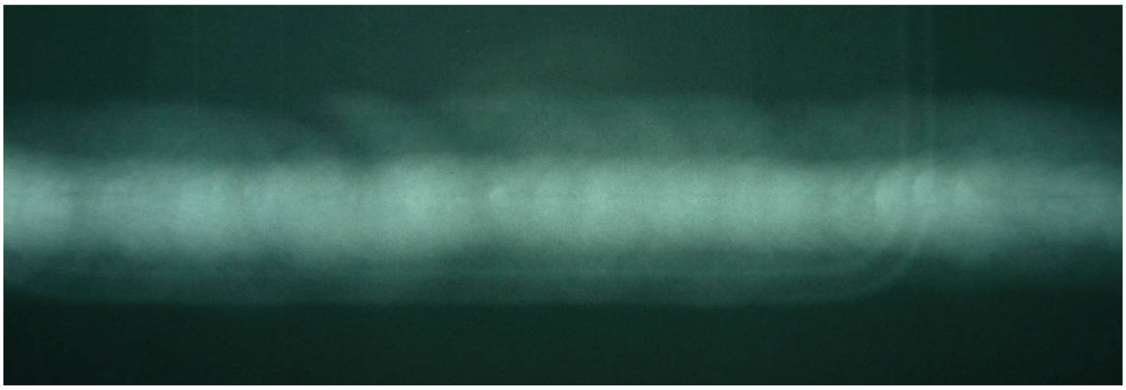


Figure 6: X-ray picture from the cracks

3.3 Oxygen, humidity and, nitrogen in mild steel

The contact of oxygen to iron leads to oxidation. The oxides form a slag witch is lying on the surface of the seam. Normally it is no problem. But as the oxides are easier then the liquid iron they also may rise through the melt pool and cause the same problem as when welding aluminium.

Mild steel is also sensitive to nitrogen and humidity. Above 590 °C iron can solve up to 0,1 % nitrogen. At room temperature the solubility decreases down to nearly zero. By forming intermetallic phases embedding nitrogen ions between grain boundaries it causes the embrittlement of steel. The hardness raises and the ductility decreases enormously.

The pictures below show the effect of back shielding. you can see the oxidation and the undercuts.

Figure 7: Tube root with back shielding

Figure 8: Tube root without back shielding

Hydrogen gets solved in form of ions in liquid and hot iron. When iron gets cold the ions form molecules again without leaving the material. As the dimensions of the molecules are very big compared with the ions an enormous stress grows inside the material. This leads to the so called hydrogen induced cracks especially when there is further stress to the material.

3.4 Copper, brazed and welded

When brazing metals there is always a brazing solder and a flux material necessary. In this case the base material as well as the brazing solder or the flux may be affected by the atmosphere. Popular is the brazing of copper. Especially the flux oxidizes with the oxygen of the atmosphere. Some times no problem, but as quality requirements raise steadily it more and more becomes unacceptable. So many customers require back shielding in this case and also institutes like the German Copper Institute (DKI) advice to do this. When installing a pure gas system for example back shielding also is required.

The oxide layer may pollute the medium inside like gases or coolants. In the following system the oxides may damage or pollute further machines and equipment like pumps, filters, valves or measuring instruments.

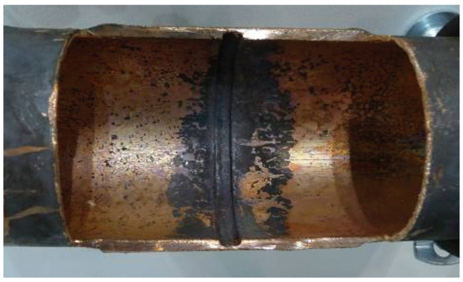


Figure 9: Brazed tube, no back shielding

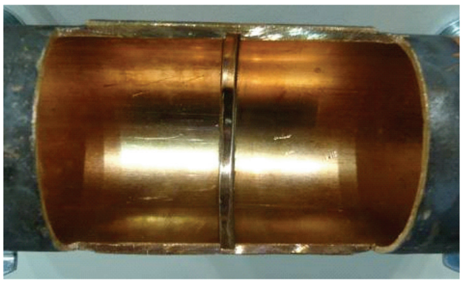


Figure 10: Brazed tube, back shielded

The welding of copper leads as expected to oxidation. This process occurs step-by-step:

$$2Cu + O_2 \leftrightarrow 2CuO,\ Cu + CuO \leftrightarrow Cu_2O,\ Cu + Cu_2O \leftrightarrow Cu\text{-}Cu_2O\text{-Eutectic}$$

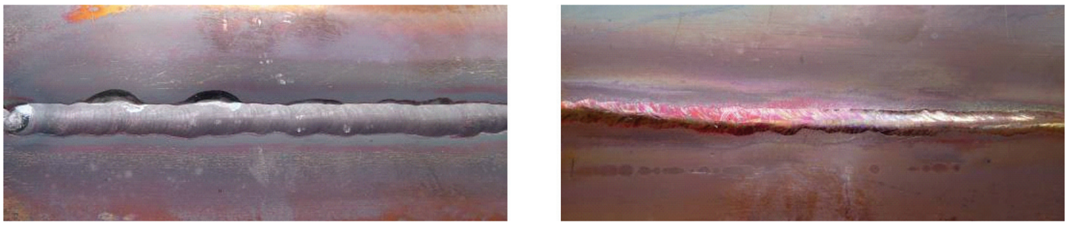


Figure 11: Copper with and without back shielding

This eutectic is located at the grain boundaries and causes embrittlement. The now oxygen containing copper is sensitive to hydrogen. The copper oxides and hydrogen form steam:

$$Cu_2O + H_2 \leftrightarrow 2\ Cu + H_2O$$

As the steam needs much more room as the oxygen of the oxides it occurs to big cracks. This is the so-called "Wasserstoffkrankheit" (hydrogen embrittlement).

3.5 Magnesium

The reaction of magnesium with the atmosphere is very intensive. When welding magnesium and it reaches its ignition temperature magnesium starts burning. The chemical reaction equation is:

$$2Mg + O_2 \leftrightarrow 2MgO$$

This reaction starts at 500 °C. Further reactions with nitrogen and humidity are possible:

$$3Mg + N_2 \leftrightarrow Mg_3N_2$$

$$Mg_3N_2 + 6H_2O \leftrightarrow 3Mg(OH)_2 + 2NH_3$$

As we have different temperature gradients and variable humidity concentrations Magnesium can react in several ways. To reach quality seams magnesium can only be welded in so-called shielding gas or welding boxes. These boxes are very popular. As shielding gas Argon 4.8 (99,998 % Argon) should be used. Some customers prefer Argon 5.0.

Figure 12: Welding box

3.6 Titanium

Titanium is a little bit similar to magnesium. It can react to titanium nitride (TiN), different titanium oxides (TiO, TiO_2, Ti_2O_3) or titanium hydride (TiH_2). Titanium nitrides occur above 1200 °C. The density of titanium is 4,5 g/cm³ and the density of the nitrides is 5,2 g/cm³. As the difference is not very high the nitrides get mixed with the liquid titanium.

$$2Ti + N2 \leftrightarrow 2TiN$$

Especially titanium nitride and hydride lead to embrittlement. This will cause cracks after a short life time. Also titanium often gets welded in welding boxes to prevent it from reactions with the atmosphere.

After contact with nitrogen, oxygen or hydrogen (as a result of humidity) it is not possible to remove impurities by brushing, grinding or etching. The impurities get mixed with and are a part of the microstructure. So it is necessary to cut away the seam and weld it again.

4. Back shielding – Proceedings

To produce welds with a high quality economically you should follow some basic rules.

4.1 Laminar stream

One of the most important principles concerning the supply of shielding gas to the welding area is to ensure a controlled transport from the hose to the welding area. A laminar stream of the shielding gas is the basis to this.

A turbulent stream leads to a mix of shielding gas and air. If you now have to shield a whole vessel from inside it is nearly impossible to reach an atmosphere without oxygen, nitrogen or humidity.

A laminar flow can be generated using a diffuser. As a diffuser tubes, sheets or molded parts made of sintered material can be used. Through the sintered metal, the gas supply is distributed over a large area whereof the shielding gas can flow out laminar. In an emergency, a construction made of perforated sheet metal and steel wool may be helpful.

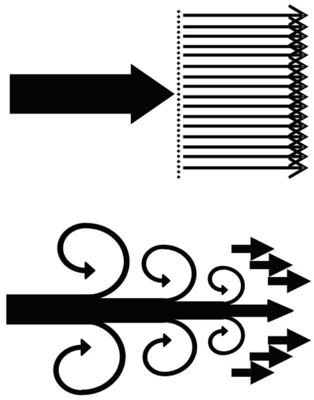


Figure 13: Laminar and turbulent stream

4.2 Gases lighter or heavier than air

The difference of the different gas mixtures is also caused by the difference in density between air and shielding gas. The back shielding procedures can roughly be divided into:

- back shielding upwards – with gases heavier than air
- back shielding downwards – with gases lighter than air
- back shielding with gases, same density than air.

When using gas mixtures with a higher density than air, the vessel must be filled from the bottom to the top. This means that the container is filled from below and has a vent at the top, through which the repressed atmosphere is derived. For gas mixtures with a lower density than air, the mechanism works in reverse.

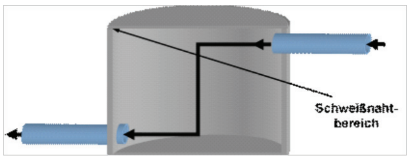


Figure 14: Back shielding from top to bottom

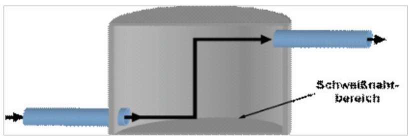


Figure 15: Back shielding from bottom to top

The selection of the process can depend on the shielding gases present on the spot or can depend on technical requirements as for example the location of the welding area. When filling a vessel from the bottom to the top the required oxygen free area first is reached at the bottom.

4.3 Back shielding of pipes

Back shielding of pipes, especially at larger diameters and changing directions, leads to a typical problem. For larger pipe diameters and a very different density of the forming gas from the air, different problems can result from the fact that primary the gas mixtures tends to rise or settle. In another case, when using a light gas mixture in a rising pipe section, it may lead to a mixing with the existing atmosphere without having displaced the entire atmosphere. In order to prevent this, gas mixtures with the same density as air can be used. This is possible by using argon / nitrogen / hydrogen mixtures of different compositions. The relation between argon and nitrogen can be tuned to the hydrogen content.

5. Hoses

Another important component is the shielding gas hose itself. When selecting a hose attention must be paid to the suitability of the hose for back shielding. Commercially available PVC tubes, originally meant to transport compressed air, are not suitable for this task. These hoses are able to dilute humidity from the atmosphere and transport it to the dry gas. The so absorbed humidity at higher temperatures gets split into hydrogen and oxygen in the seam area. This oxygen produces oxidation of the weld area. Tubes manufactured fulfilling the requirements of DIN EN 559 are available at every good welding accessories shop. Savings can be very expensive at this point.

6. Back shielding gases

As we know that the different materials may be sensitive to different gases we have the following range of possible back shielding gas and gas mixtures:
- Nitrogen
- Nitrogen / hydrogen mixtures
- pure Argon
- Argon / hydrogen mixtures
- further mixtures

Nitrogen / hydrogen mixtures are very popular. Materials witch are not sensitive to nitrogen or hydrogen can be welded with them. Gas mixtures with more than 4% hydrogen are able to form flammable mixtures with air.

6.1 Choice of gases

All popular gas mixtures are based on argon or nitrogen. To reduce the residual oxygen hydrogen gets mixed into the gas mixtures. Also helium can be added to reach a special density. Now we have three main criteria to choose a shielding gas:
1. the density of the shielding gas – heavier or lighter than air
2. the material – possible incompatibilities
3. hydrogen for reducing residual oxygen.

6.1.1 The density of shielding gases

Regarding the density we have the following types of mixtures:
- gas mixtures lighter than air
- gas mixtures heavier than air
- gas mixtures same density as air.

Nitrogen is lighter than air; argon is heavier than air, adding hydrogen in both cases leads to a lower density. These facts are interesting for choosing the right back shielding direction. So it has to be regarded when choosing the direction or when choosing the shielding gas.

6.1.2 The material and possible incompatibilities

As described there are a few incompatibilities between materials and gases. The components of the forming gases can damage the material by forming nitrides, oxides, or hydrogen induced cracks. So this must be regarded when choosing the right shielding gas. In DVS-Merkblatt 0937 we can find a table with some advises. As argon is a very universal shielding gas nitrogen and hydrogen sometimes are problematical in use. Even when welding mild steel nitrogen/hydrogen mixtures may cause problems

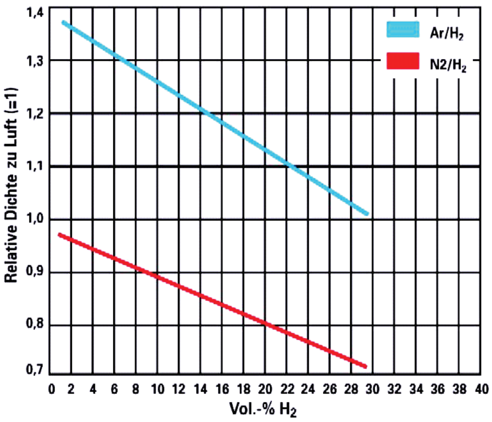


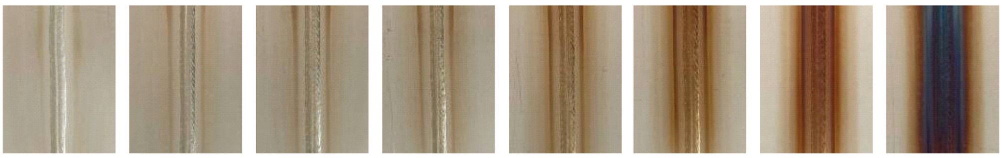
Figure 16: Density of different gas mixtures

shielding gas	material
argon	Austenitic Cr-Ni steels, austenitic-ferritic steels (duplex), gas sensitive materials (titanium, zirconium, molybdenum), hydrogen sensitive materials (highstrength, fine-grained construction steels, copper and copper alloys, aluminium and aluminium alloys and other NF metals), ferritic Cr steels
argon/hydrogen mixtures	Austenitic Cr-Ni steels, Ni and Ni-based materials
nitrogen	Austenitic Cr-Ni steels, austenitic-ferritic steels (duplex)
nitrogen/hydrogen mixtures	Steels (with the exception of high-strength, fine-grained construction steels), austenitic Cr-Ni steels

Figure 17: Advisable combinations

6.1.3 Hydrogen in back shielding gases

When loading a tank or pipe with shielding gas – even when working in a very precise way - it comes more or less to a small mixing with the atmosphere. This applies especially to irregularly shaped vessels. This mixing with the atmosphere leads to the so-called residual oxygen who leads to the oxidation of the surface of the root and the heat affected zone. The degree of oxidation is characterized by annealing colours.



0 10 18 28 49 73 97 150

Figure 18: Annealing colours depending on residual oxygen (ppm)

With continuing back shielding the residual oxygen content gets reduced. Depending on the material it is necessary to decrease the oxygen content under an acceptable maximum oxygen content before starting the welding process. Usually this is around 20-50 ppm when welding stainless steel. The residual oxygen content can be influenced by the purging time in most cases.

The measuring of the residual oxygen content can be done using a suitable measuring device.

If the oxygen content can't be reduced as much as required the use of hydrogen containing mixtures is possible. Hydrogen reacts with the residual oxygen to water.

6.2 Flammability Limits

Most important, the final consideration is "How much hydrogen is neccesary for my back shielding process?" Depending on the hydrogen content forming gases are flammable in air. These must be burned off at the exit from the vessel or tube. The ignition limit is 4 % H2.

As written in DVS-Merkblatt 0937 mixtures have to be burned off from 10 % H2. Differences are made between self- and not self-burning gases. When using not self-burning mixtures using a pilot flame is required.

One risk with the use of combustible shielding gases is the explosion. This is given if at the beginning of the welding work already a flammable mixture of shielding gas and air remains in the vessel. The mixture is in the so-called ignition area (Figure 19).

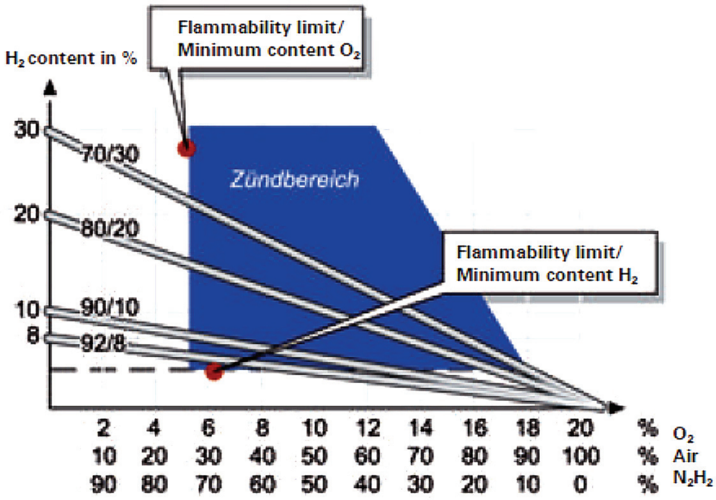


Figure 19: Flammability limit

The forming gas / air mixture composition in the vessel changes continuously during the loading and thereby passing a flammable range. Depending on the shielding gas mixture the range is different. The diagram shows the flammability range of different nitrogen/hydrogen mixtures. For safety reasons, the general statement can be made that the content of the vessel has to be minimum 75 % of forming gas before you can start welding. The oxygen content in the vessel is then less than 4 % and the forming gas / air mixture is not ignitable. For technical reasons the oxygen content is much too high to produce seams without oxidation and without annealing colours.

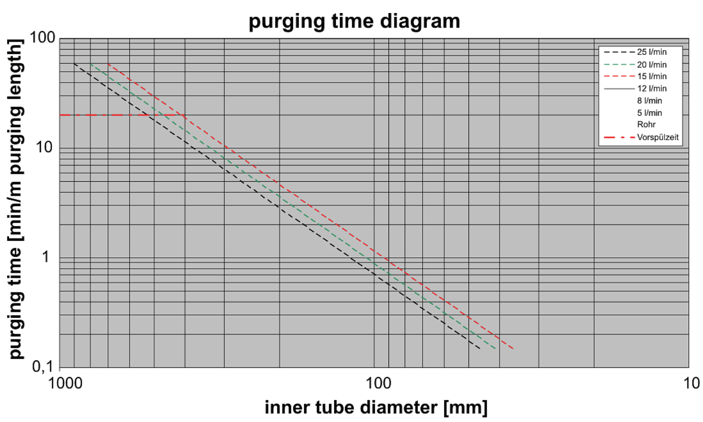


Figure 20: Purging time diagram

6.3 Purging

The purge time for the various components is in the correct procedure only depending on the residual oxygen content required. That is, the more sensitive the material, the longer the purge time. For sheets and irregular vessels, the residual oxygen content is measured and the purge time can be determined empirically. For the shielding of pipelines, there is a graphic representation as a reference point (DVS-MB 0937) for the determination of a sufficient flushing time (Figure 20). Depending on pipe diameter, the flushing time per running meter of pipe can be determined

7. Residual components of the air and impurities

If not the whole atmosphere gets replaced from a tube or vessel nitrogen, oxygen and humidity are the residual components. As the supply system has many possible leakages the shielding gas itself may be polluted on its way to the back shielding area. Otherwise the welding area and the wire may be polluted.

Summary of sources for impurities:

1. Air – wire guide
2. Air – the torch
3. Air – magnetic valves
4. Humidity and Air – Tubes and Hoses
5. Humidity – Welding wire (especially in case of aluminium) or welding powder
6. Grease
7. Primer.

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