

Purging while welding

Purging can enhance your weld quality by improving corrosion resistance

Contents

- 03 Introduction
- 04 Temper colours and corrosion resistance
- 07 Classification and action of backing gases
- 08 Criteria for selection of the shielding gas
- 10 Purging techniques, purging rate, effect of pipe length
- 12 Purging hardware and measuring instruments
- 13 Condensation films, 'manganese streaks'
- 14 Supplying gas via hoses
- 15 Workplace safety while purging
- 15 References



Introduction

The primary reason for the wide use of stainless steels is their general corrosion resistance. To ensure the operational safety of weldments of high-alloy steels under corrosive conditions, it is further necessary to maintain the special characteristics of these materials when producing welded joints. The exposure to heat and oxygen during the welding process results in the formation of temper colours on stainless steels and other materials (e.g. titanium). These are bands of various colours around the penetration bead and adjacent parent material that can severely reduce the corrosion resistance of high-alloy materials, and usually must be avoided or removed.

Methods for removing temper colours are classified as chemical, electrochemical and mechanical. Pickling, a purely chemical process used to remove temper colours and other impurities from the workpiece surface through treatment with a mixture of various acids can often not be employed for reasons of availability and environmental protection. Devices for electrochemical removal of discolourations require manual operation and are therefore only practical for use with smaller workpieces. When blasting or using mechanical techniques (grinding, brushing) accessibility permitting, the required degree of removal or cleaning effect is often questionable. In addition, there is always the risk that stainless and non-alloyed steel materials may be unintentionally mixed up. Shielding the weld root with an inert gas—via purging—presents an alternative to these methods. Several aspects of the application and peculiarities of this technique are described in the following.

Temper colours and corrosion resistance

The corrosion resistance of stainless steels results from a very thin, strongly adhering but easily destroyed chromium oxide layer on the surface that forms on its own upon exposure to oxygen (e.g. exposed to air) and is designated as a passive layer. Formation of this passive layer requires a chromium content greater than approx. 11%; the layer thickness is about 5 to 10 nm. If this layer is destroyed or damaged, by scratches, for instance, the layer reforms after a brief period of time if an adequate supply of oxygen is available and the formation process is not disrupted by other surface films.

Temper colours are formed through the **simultaneous** exposure to heat and oxygen. They appear as colourful streaks parallel to the weld seam. The colourful appearance is produced by interference resulting from the reflection and refraction of light. During the formation of temper colours, the normal passive layer on the material is changed by the oxidation and diffusion processes, specifically, in terms of thickness and structure. Depending on the formation temperature and oxygen supply, the oxide layer can grow to a thickness of up to 300 nm. Reliable corrosion protection is no longer provided by an oxide layer that has been changed in this way!

Figure 1 illustrates the difference between a correctly formed and a fully unprotected, and, in this form, no longer corrosion-resistant weld root penetration bead. In both instances the same material and identical welding parameters were used.

It should be noted that, for the image on the right, the black oxidised area, can no longer be referred to as a 'temper colour', but is instead referred to as 'scale' or 'burned material', since a simple temper colour can usually be repaired, for instance, by brushing or pickling etc. Areas where scale has formed this material can no longer be restored to a 'resistant' condition by pickling; the material is ruined.

Fig. 1: Protected and unprotected weld roots penetration beads. Manual TIG, stainless steel.



The question as to which temper colours may be left untreated while still ensuring adequate corrosion resistance to pitting is now quite easy to answer. Figure 2 shows a curve illustrating the pitting corrosion potential as a function of the thickness of the oxide layer for three common CrNi materials, namely, a standard-grade CrNi steel (304), a titanium-stabilised CrNiMo steel (316Ti) and a duplex material (2205). For this experiment, the temper colours were produced over a large area in an annealing furnace under a controlled atmosphere and subsequently subjected to an electrochemical corrosion examination.

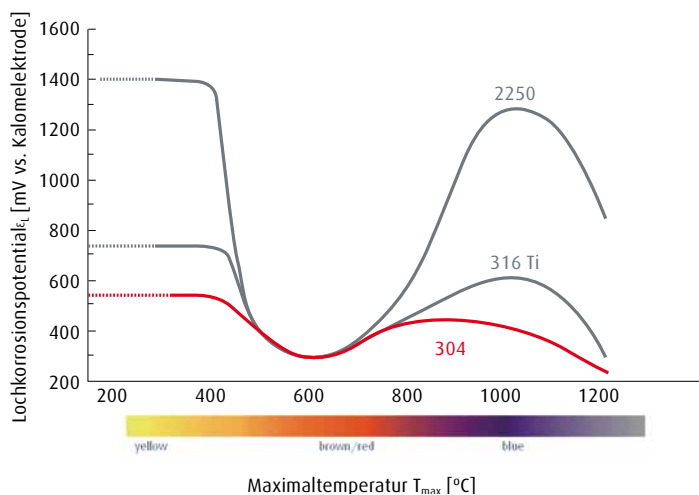
The result of this investigation is the pitting corrosion potential, an electrical parameter that indicates how resistant a material is to pitting corrosion; the higher the potential, the greater the corrosion resistance. The pitting corrosion potentials of the unaffected base materials are about 550 mV, 750 mV and 1400 mV, they approximately follow the extrapolation of the lines to lower temperatures (dotted lines). The figure shows clearly that in the area of yellow temper colours (formation temperature between 200°C and 400°C) the pitting corrosion resistance is hardly affected. In contrast, in the area of the red and red-brown colours (400°C to 800°C), the potential drops considerably to the same low value for all three materials. This means that almost all CrNi materials exhibit identical loss of resistance in red temper colour areas regardless of the alloy's composition. At higher formation temperatures, the pitting corrosion potential increases greatly once again. The values achieved there are almost as high as those of the respective unaffected base materials.

Considering the blue temper colour on its own, a reasonable corrosion resistance can be assumed. However, when welding, temperature variations between the melting temperature of the steel, on the one hand, and room temperature, on the other, always occur. The consequence is that wherever a blue temper colour appears, there is also a red area, with the corrosion resistance effects described above. The upshot is that yellow temper colours can usually be left untouched in most cases (the brighter, the better); while all other colour tones reduce the resistance significantly and must be removed. Industries where cleanliness and purity are especially important, e.g. the food processing and pharmaceutical industries, still require complete absence of temper colours in most cases.

As little as 30 ppm of residual oxygen may be enough to create temper colours. At levels below 50 ppm, formation of temper colours is usually less common; 100 ppm are generally considered a limit when processing stainless steels. Above this value, increased formation of temper colours can be expected.

In addition to the residual oxygen level, the extent of temper colour formation depends on other factors as well, e.g. the surface condition of the material and the heat input during welding. This situation is illustrated in Figure 3. The figure shows two series of tests involving TIG orbital welding of stainless steel pipes that differ in terms of wall thickness and material. It illustrates clearly that the formation of temper colours differs despite having an identical residual oxygen level in each case. It is thus not possible to specify general limits for the residual oxygen level.

Fig. 2: Pitting corrosion resistance as a function of oxide layer thickness [2] (WS = PRE = Pitting Resistance Equivalent).



Temper colours and corrosion resistance (cont.)

Various methods are available for removing temper colours and achieve different levels of surface quality. They are summarised in Table 1 (without any claim to completeness).

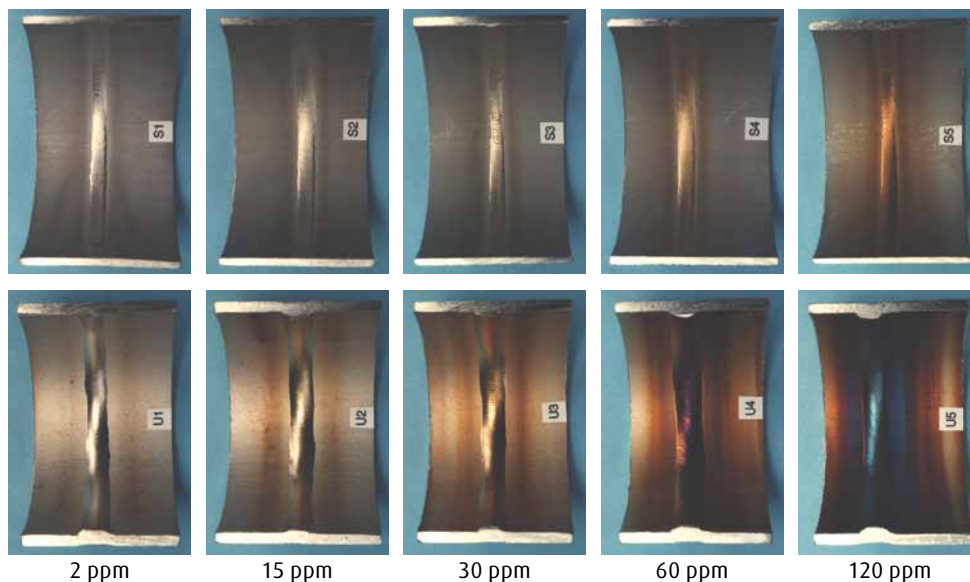
Purging, i.e. covering the weld root and adjacent parent material with a shielding gas in order to protect the penetration bead from becoming contaminated by coming into contact with atmospheric gases during and after welding, stands in contrast to the other methods mentioned here, since formation of temper colours can be prevented or greatly reduced from the outset. Purging is an economical, clean and environmentally friendly method.

The best results with regard to corrosion protection are achieved with a combination of methods, i.e. grite blasting or purging, each followed by pickling.

Table 1: Methods for removing temper colours

Method	Comments
Brushing	Minimal removal, relatively little corrosion resistance achievable
Grinding	Uniform removal is difficult, risk of local overheating
Grite blasting	Only minimal removal, preferable surface condition
Pickling	Chemical removal, very good resistance achievable, severe oxidation and slag must be removed prior to pickling
Electrochemical cleaning	Good cleaning action, but often a slow process
Purging	Little or only slight oxide formation

Fig. 3: Effect of increasing residual oxygen level at the weld root on temper colour formation



Classification and action of backing gases

The backing gases used for welding can be found together with the shielding gases for welding in ISO 14175. This Standard has been in effect since April 2008 and replaces the previously applicable EN 439. The gases commonly used for root protection are listed in groups I, R and N.

The term 'forming gas' (purging gas) actually designates specific nitrogen/hydrogen mixtures; in actual practice, however, 'forming gas' (purging gas) and 'backing gas' are used as synonyms. This should be noted to avoid any misunderstandings.

Argon and **nitrogen** act as inert gases during root protection, although nitrogen is said to slightly improve pitting corrosion resistance, especially when used with duplex steels.

The backing gas component, hydrogen, has two essential properties: firstly, it is strongly reducing. This means that hydrogen is able to bond any residual oxygen still present, and, assuming sufficiently high temperatures, can return oxides already present to their constituent elements. In combination, the pair ensures very good protection against the formation of temper colours. Secondly, hydrogen affects the surface tension of the molten material at the weld root, which provides a very good transition to the base material.

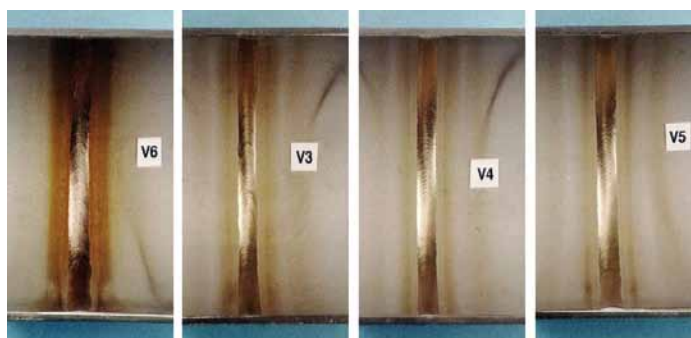
The reducing effect of **hydrogen** is illustrated in Figure 4. Each of the welds shown was welded with the same residual oxygen level on the root side, but the hydrogen level varied from 0 to 20%. This clearly illustrates that in spite of identical residual oxygen levels, the welds where the backing gas also contained hydrogen exhibit less temper colour formation.

In difficult purging situations where a sufficiently low residual oxygen level can only be achieved with difficulty, better results regarding prevention of temper colours usually are obtained with hydrogen-containing backing gases.

Fig. 4: Effect of hydrogen additions on prevention of temper colours at a constant residual oxygen level

Workpiece
Pipe Ø60.2 x 3

Material
316Ti



Backing gas	Argon + 100vpm O ₂			
	As above	Argoplas® 5 (5% H ₂ Balance Ar)	+10% H ₂	Argoplas® 20 (20% H ₂ Balance Ar)

Criteria for selection of the shielding gas

Generally speaking, ensuring corrosion resistance of the entire weld seam requires all areas affected by temperature (weld root, weld surface and adjacent parent material) where oxidation is still possible. The weld surface area must be protected until a certain temperature limit is reached. Approximate values for this temperature limit are listed below:

- Approx. 250°C for CrNi steels
- Approx. 200°C for reactive materials such as titanium, zirconium etc.

The following criteria apply for the selection of a backing gas:

- Suitability for use with the material
- Relative density of the gas
- Economic aspects, i.e. price and availability

These items are discussed in detail in the following.

Suitability for use with the material

Interactions between the shielding gas and metal can arise not only in the area of the arc, but also at a relatively cold weld root. Thus, not every backing gas is suitable for every material.

Nevertheless, there are limitations particularly with regard to hydrogen-containing backing gases. These gases are specifically not suitable for materials, such as titanium, that are sensitive to gas uptake, since this can lead to embrittlement and/or porosity formation. Nor should such mixtures be used with fine-grain structural steels with a yield point of 420N/mm² or higher, since the very fine-grained ferritic microstructure easily absorbs hydrogen and can become brittle.

With other ferritic or semi-ferritic materials such as duplex steels and chrome steels, for instance, hydrogen-containing backing gases with a H₂ content of max. 5% can be employed under certain conditions. However, measures must be taken to ensure that no hydrogen reaches the region of the arc. In such cases, welding must take place without a gap.

Another effect occurs in conjunction with nitrogen-containing backing gases, namely, the formation of yellow films on titanium-stabilised stainless steels, e.g. 316Ti / X2 CrNiMoTi 17-12-2. Here, titanium from the material and nitrogen from the backing gas combine to form titanium nitride, a yellow, very hard compound that is deposited at the weld root. This type of deposit can be distinguished from an oxide temper colour that results from inadequate purging in that it appears only on the penetration bead, and not on the adjacent parent material as well, see Figure 5. Effects of these TiN films on the corrosion resistance of stainless steels have to date not been brought to the attention of the author. If, however, discolouration-free welds are desired, the combination of Ti-stabilised material and nitrogen-containing backing gas must be avoided.

Table 2: Classification of backing gases and suitability for various materials

Backing gas	ISO 14175	Materials
Argon-hydrogen mixtures	R1 or R2	Austenitic CrNi steels Ni and Ni-based materials
Nitrogen-hydrogen mixtures ('forming gases')	R5	Austenitic CrNi steels
Argon	I1	All metallic materials suitable for fusion welding, e.g.: austenitic CrNi steels, austenitic-ferritic steels (duplex), ferritic Cr steels, gas-sensitive materials (e.g. Ti, Zr), hydrogen-sensitive materials (high-strength fine-grain structural steels, copper and copper alloys, aluminium and aluminium alloys, other nonferrous metals)
Nitrogen	N1	Austenitic CrNi steels, austenitic-ferritic steels (duplex)

Density of the gas

The different densities of the purging gases need to be considered, especially when relatively large volumes must be purged. Argon and argon/hydrogen mixtures are **heavier than air**; nitrogen and nitrogen/hydrogen mixtures are **lighter than air**. Consequently, gases with a density less than that of air should be introduced to the volume to be purged from above. This ensures that the purging gas collects at the top, and slowly displaces any air present downwards. If such a gas were to be introduced from below, the gas would rise upwards in an uncontrolled manner, become mixed with the air present, thus preventing effective purging.

For the gases that are heavier than air, the opposite applies, that is, introduction should take place from below, with air being displaced upwards.

If special purging hardware is used, e.g. when welding pipes, this effect is practically of no importance, since the value to be purged can be kept to a minimum. The importance of the specific gravity of the purging gas increases with the size of the volume to be purged.

Economic aspects, availability

Availability is naturally of great importance when making a decision for a specific backing gas. If, for instance, an argon vessel with a pipeline system is already installed, the decision to also use this readily available gas as the backing gas instead of purging gas from cylinders or packs is obvious. There are no constraints as long as the gas is suitable for the material to be welded.

Relative density of root shielding gases

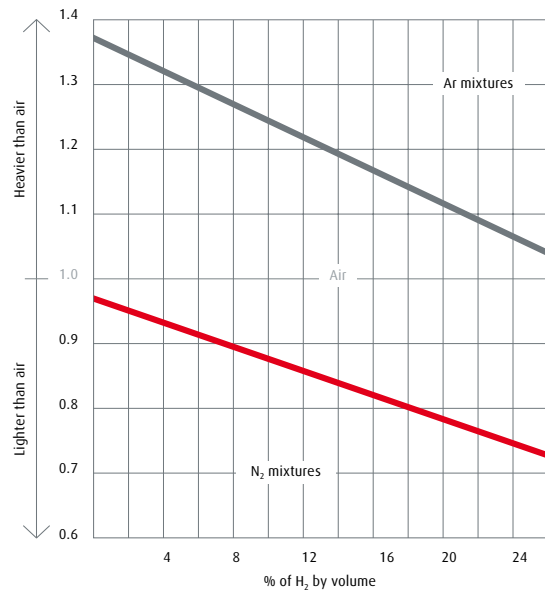
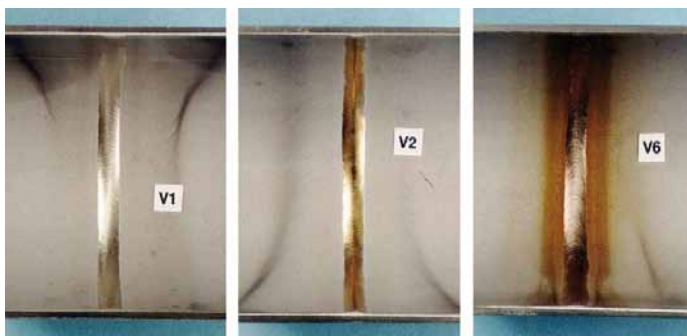


Fig. 5: Weld appearance for a titanium-stabilised stainless steel with various backing gases

Workpiece
Pipe Ø60.2 x 3

Material
316Ti



Backing gas	Argon	N ₂	Argon + 100ppm O ₂
	V1	V2	V6

Purging techniques, purging rate, effect of pipe length

The actual task when purging initially sounds quite simple: the air in a closed (or almost closed) volume is to be displaced completely by the purging gas. In actual practice, however, this task proves to be considerably more difficult than first assumed. Gases do not always behave as expected; in addition, general cost restraints often lead to the purging taking place at a faster rate, frequently resulting in less than optimal results and increased rework.

Three basic types of purging can be distinguished:

During **displacement purging**, the purging gas pushes the air to be removed ahead of it with minimal mixing. This principle can be envisioned for large containers, for instance. The density of the purging gas must be given special attention in such applications (see Ch. 4.2). In an ideal scenario, this type of purging only requires an amount of gas equal to the volume to be purged.

During **dilution purging**, the gas disperses uniformly throughout the space and mixes with the air to be removed. Purging continues until the residual oxygen level drops below a specific value. In this case, the purging gas volume required is several times the volume of the space being purged. The importance of this factor depends on the degree of mixing and the desired residual oxygen level, and cannot be determined exactly.

Evacuation purging is seldom used in the manufacturing industry. With this method, the volume to be purged is initially evacuated to the greatest extent possible and then flooded with the purging gas. If necessary, this process can be repeated several times. In addition, it must be ensured that the container or vessel is vacuum-tight, so that it does not collapse during the evacuation.

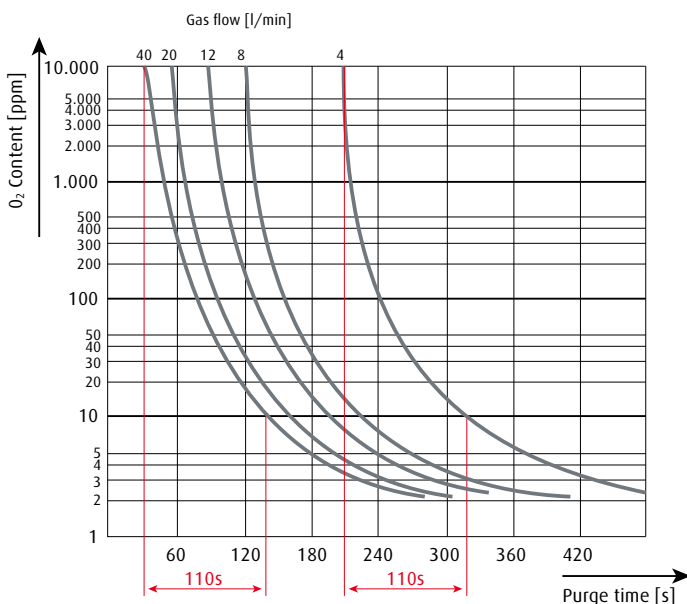
It is recommended to always try to employ displacement purging for almost every purging application. It normally involves the least amount of gas and time. However, this type of purging is not always possible in actual practice, sometimes the workpiece geometry is too complicated. It may also occur that what was intended to be displacement purging becomes dilution purging because of improperly set parameters, for instance, because the gas flow rate was set too high (-> turbulence) or the gas was introduced from the wrong direction (-> density).

The term **purging rate** does not have an exact definition. Typically, it is understood to mean the general efficiency of the purging process on the basis of the required volume of purging gas and required length of time.

At first glance, the following relationship exists between the purging time, the volume to be purged and the gas flow rate:

$$\text{Purging time} \approx \frac{\text{Purged volume}}{\text{Gas flow rate}}$$

Fig. 6: Effect of gas flow rate on the purging time



Pipe length: 6m
 PipeØ: 60.3mm
 O₂ content in air: 20.9%
 Gas inflow over the full diameter via sintered metal
 0.4m plastic hose
 30.0 Cu-and stainless tube
 Purge Gas – Argon

According to this relationship, doubling the gas flow rate cuts the purging time in half. The truth is actually somewhat different, since with large amounts of gas and at high flow rates, turbulence occurs at both the purging gas/air interface and the walls of the workpiece. This turbulence results in mixing and thus a lowering of the purging rate. The results of this turbulence can be seen from the following experiment:

To determine the purging action and the current residual oxygen level, the reduction in the O₂ content of the purging gas was measured for different amounts of gas and flow rates in identically sized pipes, Figure 6. In this experiment, the length purged was 6 m and the pipe diameter 60.3 mm. Argon was used as the purging gas. The first measurement of the purging time was completed upon reaching an O₂ content of 104 ppm = 10,000 ppm = 1%. At a gas flow rate of 4 l/min, this value was reached after 210 s. After doubling the gas flow rate to 8 l/min, it was possible to reach the 1% O₂ limit approx. 90 s sooner. To save an additional 90 seconds, however, the gas flow rate cannot be doubled but must instead be increased fivefold to 40 l/min, as can be seen in the diagram. The purging rate is thus **not absolutely** proportional to the value of the gas flow rate.

Let us now examine the purging action of various gas flow rates below 1% oxygen, namely, in the region between 1% and 10 ppm. At a flow rate of 4 l/min, the 1% O₂ limit was reached after 210 seconds; the 10 ppm level, after approx. 320 seconds. The difference between these is approx. 110 seconds. If the flow rate were increased tenfold, namely, to 40 l/min, 1% O₂ is reached after 30 seconds, 10 ppm after approx. 140 s. The difference between 1% and 10 ppm O₂ purging is also 110 seconds in this case! In this example, it would therefore be practical to first remove the largest amount of oxygen in the shortest length of time using a high gas flow rate, and then reduce the gas flow rate. The amount of purging gas consumed can be reduced considerably in this way without incurring any significant time loss.

Purging can enhance
your weld quality by
improving weld surface
appearance



Purging hardware and measuring instruments

Purging hardware

The market offers quite a large assortment of purging hardware. Figure 7 shows a straight design that can be introduced from one end. The gas discharge consists of a cylindrical body made from sintered metal. The sponge-like sintered metal is very porous and thus permeable to gas. It is intended to provide the most diffuse gas discharge possible and thus create a uniform laminar flow.

Similar devices are also available with a flexible centre section to permit passage of the device through pipe elbows. Additional versions are available with two instead of one set of sealing lips to provide better sealing and prevent tilting. Depending on the material quality, the sealing lips are temperature-resistant up to 280°C – 330°C.

Double-disk purging devices that are supposed to confine purging to a small area to the left and right of the weld often have a discharge opening that is too small— most likely in an attempt to conserve gas. As a consequence, the purging gas tends to escape through the weld seam gap. As this gap is closed, pressure rapidly builds up in the purging compartment and the weld, which has not yet solidified, is blown out. For instance, the pressure of an approx. 50 mm water column is already enough for a 60x3 mm pipe.

Measuring instruments

The effect of even minimal amounts of residual oxygen on the general corrosion resistance of stainless steels has already been shown in Chapter 2 ‘Temper colours and corrosion resistance’. To obtain reproducible purging results, use of residual oxygen measuring instruments is advisable.

In actual practice, ‘homemade solutions’ are often employed to determine when the residual oxygen level has dropped below a certain value and welding can begin. For instance, the flame from a cigarette lighter is often held at the gas discharge or at the welding location to ‘check’ whether welding can already start. These ‘homemade solutions’ are not recommended and are often questionable from the standpoint of safety. At best, they provide information as to whether backing gas is being discharged at all, but nothing about the residual oxygen level at the root.

Various residual oxygen measuring instruments are available on the market. Two things should be kept in mind when making a selection:

The unit must have an adequate measuring range. The minimum residual oxygen level that can be measured should be below 10ppm. Units that can only display to 0.1% (=1000 ppm) are not suitable for this purpose.

The unit should have the ability to switch between hydrogen-containing and non-hydrogen-containing backing gases. With the sensors commonly employed, hydrogen can affect the accuracy and speed of the measurement, a fact that can be compensated for electronically when switching.

Figure 8 presents a selection of various measuring instruments by way of example. Depending on the design, the residual oxygen level can be displayed numerically or via an LED display. On some instruments, it is also possible to set an alarm that signals when the level exceeds or drops below a specific value.

Fig. 7: Example of a BOC purging device for straight pipes

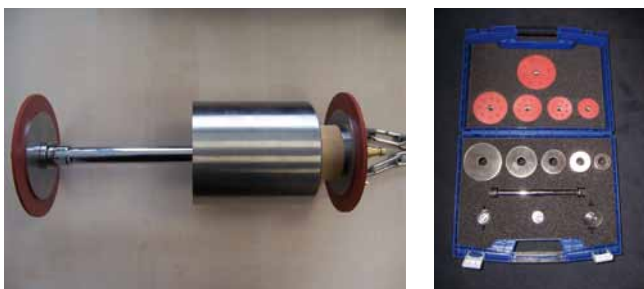


Fig. 8: Various types of residual oxygen measuring instruments (left: PBI-Dansensor – centre: Huntingdon Fusion – right: Orbimatic)



Condensation films, 'manganese streaks'

Occasionally, brown- or yellow-tinged discolourations appear next to the weld when welding pipelines. This can even occur when purging has been performed properly and the penetration bead itself displays no temper colours. What is characteristic about this type of discolouration is that it appears only in a narrow region next to the weld and often only on one side. In this case, the discolouration appears on the side of the root opposite the gas flow direction. Figure 9 shows the typical appearance of such a film. The discolouration next to the penetration bead can be seen, while the weld root bead is clear from discolouration.

The cause of such discolouration has yet to be clarified satisfactorily. It is assumed that metallic vapours are involved which have their origin in the base material, these are released at a relatively low temperature below the melting point of the base material and become entrained in the stream of gas and then condense on the colder regions next to the penetration bead.

Experience shows that these films can appear in a wide variety of forms. Usually they are firmly adhering, but there are also instances where they can simply be wiped away with a cloth. There are also reports of the discolouration appearing only after a certain period of time has elapsed. In one example, the penetration bead appeared perfect and without any discolouration immediately after welding, although the characteristic streaks appeared several hours later.

It seems that the mechanism that gives rise to these discolourations is considerably more complex than what can be explained by simple condensation. The effect of such films on the corrosion behaviour of the steel also remains completely unclarified. It has not even been confirmed unambiguously that there is any effect. Nevertheless, such condensation films are still cause for complaints, especially in applications where the weld must satisfy extremely high standards, for instance, lines in the food processing and pharmaceutical industries.

Experience has shown that changing the backing gas has no effect on such films. They appear regardless of whether argon, nitrogen or forming gas is used. An approach that promises to prevent such films is based on use of special purging hardware that accelerates the stream of gas close to the pipe wall. In this way, it seems possible to 'blow away' the substances responsible and prevent appearance of the discolouration. It must be emphasised, however, that this approach does not really make the deposits disappear, but rather merely distributes them over a larger surface area inside the pipe where they are no longer visible.

An additional way to avoid such deposits is to work with minimal heat input and the smallest possible weldpool. This is possible when employing TIG orbital welding, for instance, by welding with a so-called step program, i.e. the torch moves in steps and creates a spot weld only during a brief stop.

Fig. 9: Typical condensation film next to the weld, referred to as the 'manganese streak'



Supplying gas via hoses

The impermeability or diffusion of gas hoses is often assessed incorrectly. Depending on the quality of the hose used, hoses exhibit more or less diffusion of oxygen or moisture into the interior of the hose. Contrary to a widely held belief, it does not matter whether the hose is pressurised or not. The only relevant factor is the concentration difference of moisture and oxygen between the gas inside the hose and that outside the hose, or more precisely the difference in partial pressures.

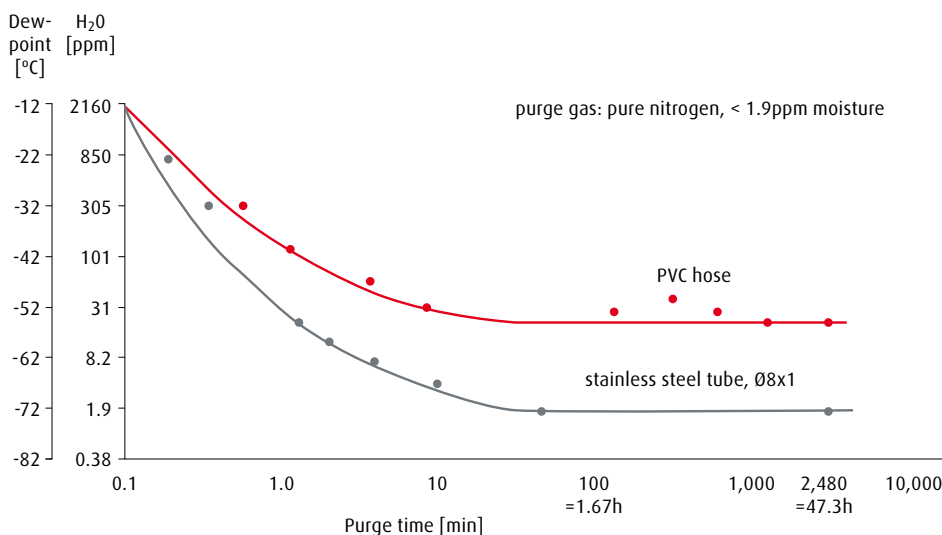
PVC hoses, for instance, exhibit relatively high diffusion rates. If such a hose were to be left lying on the factory floor, possibly in a puddle, over the weekend the purge gas that flows through this hose will have a high moisture level on the next working day and cause problems when welding. PVC hoses, in particular, slowly release the accumulated moisture through the gas stream over a long period of time, so that brief flushing into the atmosphere does not help.

Figure 10 clearly illustrates that under certain circumstances the residual moisture level at the hose outlet can still remain very high even after flushing with a dry test gas (moisture level below 1.9 ppm) for days.

It is now possible to find specially developed gas hoses on the market that are characterised by extremely low diffusion rates. Use of these hoses is particularly recommended when the requirements for gas purity are very high, for instance, when working with aluminum or titanium. In the interest of having a lower defect rate, using the higher quality more expensive hoses rather than the inferior standard hoses should be considered.

A general recommendation is to use stainless steel piping for the gas line as far as possible to avoid contaminating the gas, especially with moisture. Quick-disconnect couplings in the supply line should also be avoided whenever possible.

Fig. 10: Release of moisture into the backing gas by contaminated hose material



Workplace safety while purging

When performed properly and basic safety rules are observed, purging is a very safe procedure. There are, however, several aspects that require particular attention to prevent accidents.

Working with purging gases essentially involves two risks:

- The formation of combustible mixtures when working with hydrogenous backing gases
- Suffocation or asphyxiation resulting from excessive use of large amounts of gas and/or inadequate ventilation

If hydrogenous backing gases are used, care must be taken to ensure that no combustible mixtures form with air. For a combustible mixture to form at all, certain minimum levels of air and hydrogen are required. While it is quite possible to form combustible mixtures with a 90/10 (90%N₂ + 10%H₂) purging gas, this is practically impossible with a 95/5 (95%N₂ + 5%H₂) purging gas. BOC recommends burning off the discharged purging gas when working with a hydrogen content of 10% or higher.

To prevent suffocation, the same recommendations that apply in the case of shielding gases should be observed. Purging gas is odourless, colourless and tasteless. For people who are not aware, suffocation by inert gases occurs without any prior detectable indication. Where necessary the use of meters should be considered to warn of a change in the atmosphere before oxygen levels fall to a potentially hazardous level

Great caution must be exercised, particularly when working in confined or poorly ventilated areas. When purging large volumes, it must also be noted that relatively large amounts of gas are needed. If, for instance, a container with a capacity of several cubic meters is to be purged completely, all of the backing gas should not suddenly be released into the plant upon completion of the welding; instead, the container should be vented slowly. Two different scenarios can be distinguished in this and in similar situations:

The purged volume, i.e. a large container, is filled with a **non-hydrogen-containing** inert or quasi-inert backing gas (e.g. nitrogen). In this case, the purged volume should be flushed slowly with air upon completion of the welding to prevent large amounts of nitrogen from suddenly being released into the factory. This could lead to a shortage of oxygen and, in the worst case, suffocation.

The purged volume is filled with a **hydrogen-containing** backing gas (e.g. 90/10 forming gas). In this case, purging with air should not be completed under any circumstances, because a combustible mixture could otherwise form inside the container. On the contrary, it is recommended to first flush with nitrogen and then ventilate as in example 1. In this case as well, the sudden release of large amounts of forming gas into the working environment must be avoided to prevent formation of combustible mixtures.

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