

Improving Quality when Welding Stainless Steel Pipe

Minute traces of oxygen during welding can have profound effects on the serviceability, life, and appearance of the joints

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Stainless steel, titanium, and other gas-sensitive metals are being used for an amazing variety of applications from ornamental handrails to piping used in the petrochemical, food, semiconductor, nuclear, and chemical industries. Beside looking esthetically pleasing, these metals also have a very valuable characteristic. When welded correctly, these metals can be used in contact with corrosive or sensitive materials without contaminating them, thus making them the number-one choices for applications requiring long service life and non-contamination.

The importance of purging the joint with argon or an inert gas mixture is well known to most welders when joining gas-sensitive metals. Welders recognize the blue tinge on their welds as a sign of oxidation caused by exposure to oxygen. This oxidation is a form of corrosion that can be traced back to inadequate purging. This problem, though well known in the welding industry, is not as well understood by workers in some manufacturing plants in the petrochemical, food, semiconductor, nuclear, and chemical industries.

Industry has fortunately moved from welding critical gas-sensitive metals with gas metal arc welding (GMAW) to gas tungsten arc welding (GTAW), but there is still a long way to go. Welding procedures often do not adequately detail the requirements for proper purging. Most welding is done to comply with a code while documentation for purging is inadequate or lacking altogether.

The most critical piece of a piping job, after the selection of pipe schedule, is the quality of the weld. If the weld has oxidized, it will be much weaker and may fail and/or cause contamination of the product. Repairing oxidized pipe is costly.

To avoid oxidation while welding, the oxygen remaining in the purged atmosphere (rest oxygen) ideally

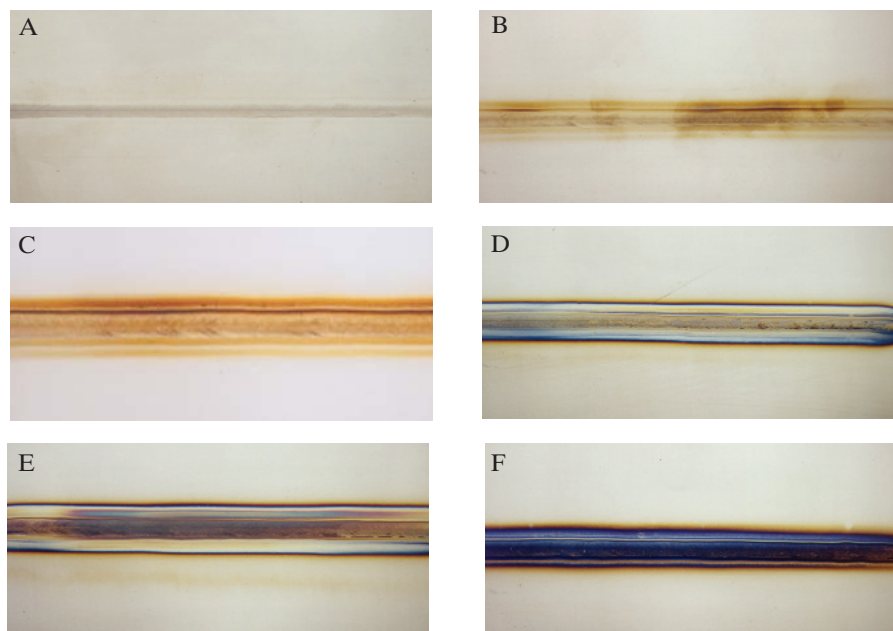


Fig. 1 — Photos showing oxidation of 316L stainless steel coupons welded using argon purging gas with rest oxygen levels of: A — 12 ppm; B — 60 ppm; C — 70 ppm; D — 200 ppm; E — 250 ppm; and F — 500 ppm.

should be 0. Oxidation is commonly called “sugaring” when welding stainless steels and chrome-nickel steels. This oxidation is even more serious when welding titanium, zirconium, molybdenum, and some other gas-reactive metals and alloys. The resulting oxidized surfaces are no longer corrosion resistant and further treatment may be necessary.

Removing the oxidation using mechanical means, such as grinding, also removes the metal’s passive protective layer. This passive protective layer is only 20 angstroms thick and must either be protected or restored. Other mechanical procedures, such as brushing, blasting, or

pickling, can remove the oxidation and restore the metal’s resistance. However, in some cases, such as for pipes, this is difficult or impossible to do. The best solution is to prevent the oxidation from occurring in the first place by removing the oxygen. The purging gas is usually a heavier-than-air inert gas such as argon. This purge gas displaces the oxygen during welding then shields the welded joint from oxygen until it has cooled.

When welding any gas-reactive metal, it is imperative that the rest oxygen content be below 70 parts per million (ppm) to avoid contamination or rejected welds. To give an idea of

what this value of oxygen means, the oxygen content in the air that we breathe is about 21%. For the sake of quantifying a value that is far more accurate than using percentage, we need to measure rest oxygen in units of parts per million. For example, 21% oxygen would equal 210,000 ppm, and if the rest oxygen value is 0.1%, it equals 1000 ppm. If the value is without the term rest oxygen, it could signify air and consequently, the value would be hard to quantify with any accuracy. If we use the term rest oxygen and the value is 0.01%, this would be 100 ppm and consequently, 0.0001% would be 1 ppm. This means that a 70 ppm sample reading indicates there would be 70 parts of rest oxygen left in a sample size of 1 million parts of gas. This value sounds very low, but looking at the pictures of the rest oxygen levels, 70 ppm still gives considerable discoloration. Coupons made from 316L stainless steel were welded at various rest oxygen levels and photographs were taken of the welds — Fig. 1A–F. (Note: A titanium weld made at 12 ppm would be much more discolored than what is shown here for stainless steel.)

Selvaduray and Trigwell (Ref. 1) wrote in their article on welding stainless steel for ultrapure fluid delivery systems, “Welding of the tubing often leads to discoloration in the heat-affected zone, which can lead to corrosion.” They concluded, “The discoloration in the heat-affected zone commonly observed in welded electropolished stainless steel is caused by contamination by oxygen of the argon purge gas used during welding and is a function of the concentration of oxygen in the purge gas.” Their analysis showed an oxygen level as low as 31.6 ppm results in failure under both fluorescent and Maglite scans.

It is interesting to note that there are many oxygen indicators available that have operating ranges from either 25 to 0.1% (1000 ppm), or 25 to 0.01% (100 ppm). The units that read down to 1000 ppm are useless for the welding industry and even the units measuring down to 100 ppm are not good enough. Any serious welding application needs an indicator that can accurately measure 1 ppm (0.0001%) rest oxygen.

The two most common devices capable of measuring low levels of oxygen employ either an electrochemical-type cell or a zirconium cell.

The electrochemical cell is popular because it is lower priced and has an instant-on feature. It uses an electrolyte that is consumed during the measuring process and will eventually dry up while in storage. The electrolyte can be replenished in some units, while other lower-priced models are simply discarded when inoperative.



Fig. 2 — Newer zirconium oxide cell oxygen indicators, such as this Pro2-plus from Intercon Enterprises, offer fast warm-up times, robust housings, and the ability to measure oxygen levels as low as 1 ppm.

The zirconium oxide cell (Fig. 2) is a very accurate way of measuring the rest oxygen. While the early units required 15-min warm-up times and the fragile cells were easily damaged, the newer zirconium oxide cell units have addressed these concerns and offer quick warm-up times and robust housings to protect the cell. The big advantage with the zirconium cell is less maintenance and, depending on the type, the capability for being used around the clock, which makes it perfect for vessel work and orbital welding operations. Moreover, some oxygen indicators offer data-printout capabilities to automate documentation of each and every weld.

Documentation of the welding procedure before, as well as during, the purging process is of the utmost importance. This is an area that will see an increased activity in the next few years. Labor and material costs in all areas of construction have rocketed up to all-time highs bringing a heightened awareness to documenting everything that is done. Soon, documentation proving that

the welds were made correctly will be just as important as proving they were made to code.

Welding the joints correctly will also minimize the repair and maintenance operations that can add major costs and downtime and impede industries attempting to run at full capacity. The desired low rest oxygen levels are quickly and more easily obtained by reducing the volume of area within the pipe. This is achieved by damming off sections inside the pipe on both sides of the weld joint. Use of a purging dam system can reduce purge times down to only 1 or 2 min, instead of 30 or more min with older methods. This also reduces shielding gas consumption, costs, and improves the rest oxygen levels.

In conclusion, as the use of stainless and titanium pipe and tube is increasing year after year because of their desired properties, the increase of potential weld-joint failures and premature wear leading to costly replacement is a reality that must be avoided. The industries that demand these alloys should also demand the most exacting standards from their employees and contractors when these materials are welded. To avoid the myriad problems caused by excessive oxygen levels while welding, manufacturers and contractors are urged to examine their weld procedures, purging equipment and techniques, and monitor the rest oxygen levels prior to welding, while routinely documenting all parameters for every weld joint. ♦

Reference

1. Selvaduray, G., and Trigwell, S. 2002. Effects of welding electropolished stainless steel as used in ultrapure fluid delivery systems for the semiconductor and pharmaceutical industries. *Journal of the Arkansas Academy of Science*: Vol. 56.