TECHNICAL BULLETIN

POROSITY IN WELDS

Paul Bhadha
Sr. Technical Advisor, MTG, NANOCHEM® PBU

In many clean-welding applications, the primary concern is often porosity in welds. Porosity can result when shielding gas, air, or gaseous contaminants become entrapped in the weld puddle due to turbulence in the weld puddle. Generation of hydrogen from contaminants in the weld is a major cause of porosity during the welding of many metals, including steel and aluminum. As Figure 1 shows, molten aluminum has a high affinity for atomic hydrogen.[1] But *solid* aluminum can hold very little hydrogen. Hence, hydrogen gas is emitted as the weld puddle solidifies. If the cooling rate of the puddle is too fast, the gas can't rise to the surface but remains within the metal, causing porosity.

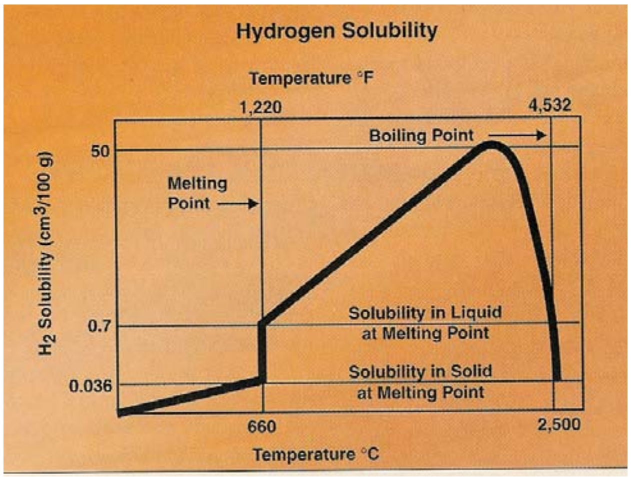


Fig. 1: Solubility of Elemental Hydrogen in Aluminum

Any compound containing the element hydrogen in its chemical / molecular formula can be a source of hydrogen that results in weld porosity. The plate or welding wire can be contaminated with hydrocarbons, such as, lubricants, grease, oil, drawing compounds, and paint. A water-cooled weld torch can easily introduce moisture to the weld through leaks at O-ring seals or fittings. Cutting and grinding operations can result in deposition of cutting fluids, saw blade lubricants, and grinding disk debris on the plate. Pneumatically-actuated grinding tools can deposit a layer of oil on the plate.

Other sources include moisture and hydrocarbons in the shielding gas, atmospheric moisture condensation on the plate or wire from high humidity and from hydrated aluminum oxide film on the plate or wire. A thin protective oxide layer forms naturally and immediately on aluminum. Moisture can be absorbed by this layer and porosity will result unless this hydrated layer is removed prior to welding. The aluminum plate needs to be degreased and dried followed by wire brushing with a stainless steel brush to remove this hydrated oxide.

Thus, porosity is caused by contaminants from many sources entering the weld puddle. Tables 2 and 3 on Page 5 of this Tech. Bulletin list some of the causes of porosity and the recommended corrective action.[1, 2, 4] Addressing these issues by following good welding practices will ensure porosity does not occur in the weld.

NANOCHEM® purifiers, marketed by Matheson Tri-Gas, Inc., find wide application in the aerospace industry for the welding of aircraft and rocket sub-assemblies from common metals such as aluminum, titanium, and stainless steels, as well as more unusual metals, such as columbium (a.k.a. niobium).

Major customers, such as United Launch (Lockheed & Boeing JV), Lockheed Martin, NASA, and other aerospace contractors use NANOCHEM purifiers on production lines and consider them an *integral* part of their welding process or a *standard operating procedure*. Some customers rely exclusively upon the purifiers for gas-line purity and consider them essential for quality control.

NANOCHEM purifiers remove most contaminants, such as oxygen, moisture, carbon dioxide, sulfur compounds, and compressor oils from shielding gases, completely and without introduction of any other compounds. The only byproduct formed by the purifier is trace hydrogen gas generated from the removal of moisture. One (1) ppm of moisture in the feed gas creates ~ ⅔ ppm of hydrogen gas after passage through NANOCHEM OMX media. The question arises whether the trace level of hydrogen gas generated by the purifier, itself, can contribute to porosity in the weld.

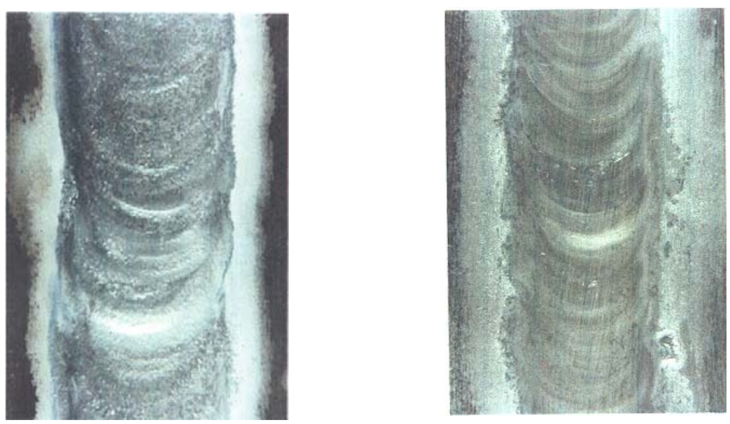
TECHNICAL BULLETIN

EXPERIMENTAL RESULTS

Results from many applications have shown that porosity is essentially eliminated by following good welding practices and the use of NANOCHEM® purifiers on shielding and backing gases:

1. **Porosity was found to be eliminated when welding aluminum (6061 T3), titanium (Ti-6Al-4V), Ferralium 255, and other alloys by the GTAW (TIG process). X-Rays were *completely* clean.** This is why many aerospace manufacturers rely upon NANOCHEM purifiers.

2. **During GTAW (TIG) welding of aluminum, welds were so ductile that they passed a 180º Bend Test without developing cracks**. Welds were smooth and uniform without any oxides.



Welding Conditions

Process:	GTAW (TIG)
Voltage:	26 volts
Current:	220 amps, AC
Weld speed:	~ 12” / min
Plate Size:	¼” x 12” x 6”
Flow Rate:	60 cfh
Impurity in Gas:	~ 40 ppm H_2O

***Without NANOCHEM* Purification**

Surface Oxides
Porosity
Poor Cleaning Action
Poor Wetting
Rough Weld Surface

***With* NANOCHEM Purification**

No Porosity, Clean X-Rays
Good Cleaning Action
Excellent Wetting
Excellent Ductility
Very Smooth Weld Surface

Figure 2: TIG Welding of Aluminum (6061 T3) with and without NANOCHEM

3. **Aluminum welds were completely free of porosity even with the GMAW (MIG) process, when using NANOCHEM purifiers and injection of NANOCHEM-purified gas through the wire guide tube / liner. Welds were as good as TIG welds in quality.** (Gas injection prevents atmospheric air and moisture from entering the weld puddle through the wire guide tube in the MIG process)

   Besides elimination of porosity with MIG process, weld spatter was greatly reduced; the weld arc was stable and less noisy with greatly reduced fumes and pyrotechnics.

   Without purification and with ~ 40 ppm H_2O in argon, MIG welds with aluminum would crack after a 20º bend. With purification, cracks were not seen even with a 180º bend.

4. Welding tests were conducted with Ferralium 255, a *duplex stainless steel* considered to be “difficult to weld.” Weld tests were conducted without gas purification and with NANOCHEM purification. Since, NANOCHEM does not remove traces of nitrogen or hydrogen in the feed argon and actually generates trace hydrogen as a byproduct, weld tests were also conducted with the same feed gas purified with a Zirconium Getter purifier (SAES St-707 equivalent: 70% Zr, 25% V, 5% Fe). Such zirconium-based purifiers remove nitrogen and hydrogen besides O_2 & H_2O from argon and helium.

   Figure 3 shows *Charpy Impact Tests* for GTAW (TIG) welding of Ferralium 255, *with* and *without* shielding and backing gas purification.

Figure 3 shows a significant increase in the weld strength from increased ductility at low temperatures (0ºF to - 75ºF) with gas purification using either NANOCHEM or Zr-Getter purifiers.

But the **NANOCHEM purifier appears to give welds of greater strength even though NANOCHEM does *not* remove nitrogen and hydrogen from argon, unlike the Zr-Getter based purifier.**

Although the scatter in the experimental data might account for some of this difference, the data shows a trend suggesting superior performance by NANOCHEM media. A possible explanation is that welds were better with NANOCHEM media because NANOCHEM OMX media is more efficient in removing contaminants, such as oxygen and moisture, due to the reaction chemistry (more irreversible reactions) and because of a higher surface area and packing characteristics (very small uniform spherical shape of NANOCHEM OMX media).

NOTE:
Zr-getter purifier size: ~ 1 liter volume
shielding gas flow rates: ~ 50 cfh (23 slpm)

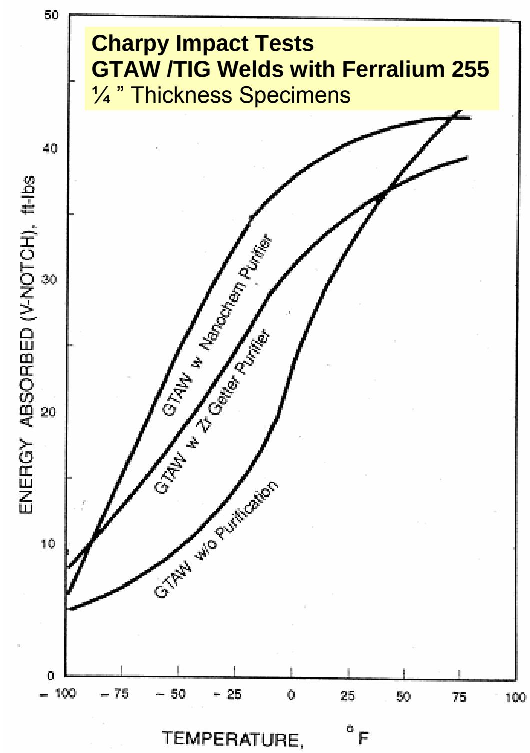


Fig 3: Charpy Impact Tests – TIG welds with Ferralium 255

5. An interesting observation was made when welding titanium (Ti-6Al-4V) with a very dirty feed argon gas containing 45 ppm O_2, 85-90 ppm H_2O and ~ 170 ppm N_2 (estimate). This gas was made by mixing a small amount of air with the feed argon containing < 5 ppm O_2 and < 5 ppm H_2O.

With gas purification: Weld puddles were crystal-clear and had a mirror-like finish. Growth of grain boundaries in the weld puddle was reduced (impurities in the melt can reduce crystal growth) Excellent weld cleaning action was observed.

Without gas purification: Welds were covered with a gold-colored oxide which became thicker and harder to remove (with a wire brush) after each subsequent pass. Weld cleaning action was significantly reduced and shades of purple were seen at the edges of the weld.

Oxygen and hydrogen levels in the weld metal were less than in the base metal, itself. The *Interstitial Analysis* of Ti-6Al-4V is given below in Table 1:

Table 1: Analysis of Interstitials in Titanium (Ti-6Al-4V)

Element	Base Metal (Ti-6Al-4V)	Filler Wire (Ti-6Al-4V)	Welds *with* NANOCHEM PURIFICATION	Welds *without* PURIFICATION
Carbon	130, 150	130, 140	120, 140	120, 80
Nitrogen	120, 130	40, 40	120, 130	110, 110
Oxygen	1420, 1500	500, 490	1230, 1060	1220, 1070
Hydrogen	45, 45	17, 23	32, 31	35, 38

With a H_2O content of 85-90 ppm in the shielding gas, NANOCHEM would generate ~ 60 ppm H_2. But the amount of hydrogen in the weld is less than in the base metal (Ti-6Al-4V), partly because of the low hydrogen content of the filler wire. **But the hydrogen content in welds *with* NANOCHEM purification is slightly lower than in welds made *without* purification. Thus, there does not seem to be any increase in the hydrogen content of the weld that can be attributed to NANOCEM media.**

6. **Indirect evidence from a customer suggests that NANOCHEM purifiers *may* remove even *micro-porosity:* Pores too small to be detected by conventional X-Rays.**

   The customer manufactures 99% nitric acid and stores the acid in tanks made of **Aluminum 3003** (1.2% Mn, 0.12% Cu). The tanks would pass X-ray radiography tests and all mechanical tests after fabrication, but still fail after as little as 1 year in service or at the most 2-3 years in service. With NANOCHEM purification, the tanks have lasted many years (over 6 years) without any failure.

   A possible explanation is that micro-pores can act as sites for crevice corrosion in the future (somewhat similar to pitting of stainless steel from contact with chloride ions) **and that NANOCHEM purification eliminates *micro-porosity*.**

CONCLUSIONS

Porosity in welds is caused by moisture and hydrocarbon contamination from many sources, including the shielding gas. Some of the causes and contributing factors for porosity and the recommended corrective actions are given on the next page in Tables 2 and 3 for GTAW and GMAW processes. [1,2,4]

Selection of the appropriate welding parameters will give a stable arc without turbulence or excessive spatter. With a stable arc and proper welding parameters, porosity is not believed to be significantly caused by hydrogen *molecules* in the feed gas, either from the gas itself or generated from a gas purifier or from hydrogen released from stainless steel hardware. It is more likely porosity is caused by energetic hydrogen *ions* generated in the electric arc from dissociation and from ionization of moisture and/or hydrocarbon molecules (from multiple sources) to form hydrogen. These energetic hydrogen ions may penetrate the molten weld metal and form hydrogen molecules in the solidified metal, causing porosity.

With a stable arc and the use of proper welding parameters, any hydrogen present in the shielding gas is unlikely to get entrapped in the weld puddle. In any case, porosity contributed from trace levels of *gaseous* hydrogen in the shielding gas is likely to be much less than porosity contributed from contaminant *liquids* (such as, condensed moisture and hydrocarbon residue) on the welding wire and the plate to be welded.

REFERENCES

1. *Anderson T., "Making the Switch to Aluminum Welding," Practical Welding Today, pg 42-47, November-December 2000.*

2. *"The Procedure Handbook of Arc Welding," Lincoln Electric Co., Cleveland, OH.*

3. *Bhadha P., "Welding of Titanium & Titanium Alloys. Preliminary Study," MTG Analytical Report, September 16, 1998. NOTE: Experiments were done at Hercules Inc.*

4. *Bhadha P., "Good Welding Practices." Information disseminated to Matheson Tri-Gas customers.*

Further Questions? Please contact:

NANOCHEM® Purification Business Unit Headquarters
1861 Lefthand Circle, Longmont, CO 80501
Tel: 303-678-0700, Fax: 303-485-0520
E-mail: MHoke@matheson-trigas.com
www.matheson-trigas.com

Table 2: Porosity in *GTAW (TIG)* Welds

Cause	Contributing Factors	Corrective Measures
Hydrogen	Oils or other hydrocarbons from lubricants and cutting fluids	Degrease with acetone or solvent. Keep acetone dry. Do not touch wire or plate with bare hands; wear disposable gloves. Avoid pneumatic-grinding tools, use electrical tools with ceramic grinders (use carbide rotary files with aluminum). But rear-exhaust pneumatic grinders may be acceptable.
	Moisture in atmosphere or moisture condensed on parts	Wipe or blow dry using pre-heat if necessary. Weld in an air-conditioned area, if needed.
	Hydrated oxide film on metal	Mechanicaly remove (wire brush with stainless steel bristles) or chemically remove oxide from weld area.
	Moisture in shielding and/or backing gas	Use gas purifier and minimize atmospheric permeation in weld hoses by proper selection of hoses / tubing to TIG torch
	Moisture from water-cooled weld gun	Check all fittings and O-Ring seals for leaks in water line
	High hydrogen content in base metal or wire	Use high-quality wire and plate with low interstitials.
	Thicker sections of plate may entrap more hydrogen	Increase gas flow to compensate for increased hydrogen in thicker sections
Incomplete Penetration	Incomplete root penetration in thicker sections increases porosity in welds	Preheat. Use higher welding current or redesign joint geometry
Temperature of Weld Puddle	Running too cool tends to increase porosity due to premature solidification of molten metal	Increase heat by maintaining proper current; adjust arc length, lower travel speed. Consider argon-helium blends (≥ 25% He) instead of pure argon for shielding.
Travel Speed	High welding speeds may increase porosity	Decrease welding speed
Solidification Time	Quick freezing of weld pool entraps gases present, resulting in porosity	Determine proper current and travel speed.
Chemical Composition of Weld Metal	Pure aluminum is more susceptible to porosity than aluminum alloys	Use suitable alloy wire to adjust weld metal composition

Table 3: Porosity in *GMAW (MIG)* Welds

Cause	Contributing Factors	Corrective Measures
Hydrogen	Oils or hydrocarbons from lubricants, cutting fluids, on electrode. Hydrated oxide film on electrode. Oily work piece.	Replace with clean, high-quality electrodes. Clean with acetone and bake at 400ºF, if needed. Do not open electrode package until ready to use. Keep elctrode supply covered.
	Oil on drive rolls or liner in MIG gun	Clean rolls with acetone, replace liner
	Entrainment of atmopsheric air and moisture through liner (wire guide tube)	Use larger-size liner and *inject* purified shielding gas into liner at very low flow rate to get highest quality MIG welds.
	Moisture in shielding and/or backing gas	Use gas purifier and minimize atmospheric permeation by proper selection of weld hoses / tubing to MIG torch
	Moisture from water-colled MIG gun	Check all fittings and O-Ring seals for leaks in water line. Replace or repair MIG guns that have over-heated.
	Spatter particles ahead of puddle	Adjust weldling parameters to minimize spatter. Use gas purifier
Erratic Wire Feeding or Burn-backs (fusion of welding wire to inside of contact tip)	Slippage on drive rolls.	Set brake tension to minimum, just enough to prevent spool from unwinding.
	Abrasion and shaving of aluminum wire.	Inlet and outlet guides and liners must be made from Teflon or Nylon to prevent abrasion and shaving of aluminum wire.
	Arcing inside contact tip can cuase build-up of particles on inside of contact tip, causing drag on wire and burn-backs.	Size ID of contact tip; if ID is too large arcing and particle build-up can occur. Replace old contact tips with deburred and polished new contact tips.
Rapid Cooling of Weld Puddle	Low rate of heat input to weld or excessive rate of heat extraction from weld.	Use higher welding current or slower travel speed.
	Low temperature of back-up bar, if used.	Preheat back-up bar, if needed. Hot back-up bars reduce porosity
	Improper groove of back-up bar.	Shallow, wide grooves are better than deep, narrow grooves in back-up bar.
Other	Partial penetration. Multiple pass welds.	Use high current density to reduce number of weld passes. Adjust weld parameters to get full penetration.