

WELDING OF ALUMINUM – THE RELATIONSHIP BETWEEN PORES AND HUMIDITY

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Abstract:

Aluminum more and more becomes an important material for building and construction. Welding is one of the most important fusion technologies and one of the most common problems is the formation of pores when welding aluminum. The cause of these pores is hydrogen. Liquid aluminum has a very high solubility for hydrogen. But during solidification the solubility decreases rapidly. The result is residual hydrogen that has not enough time to come out of the liquid melt pool and remains inside the seam as pores. Hydrogen and oxygen are the results of the cracking of humidity by the arc. There are plenty of sources for humidity like the oxide layers of the sheets and the welding wire, the adherent humidity on every surface of any part having contact with the wire or gas and last but not least the shielding gas which gets contaminated with humidity absorbed from the hoses. The different materials which can possibly be used for hose production have different properties. One of these properties is for example the permeability for humidity. At the end pores in aluminum welds can be reduced by paying attention to the sources of humidity and prevent the welding process of being influenced. If the welding process is still producing pores it is also possible to have an influence by using shielding gas mixtures.

1. INTRODUCTION

When welding aluminum the formation of pores is often referred to be inevitable: "Welding of aluminum without pores is not possible". Misleadingly very often excessively high pore contents are accepted or the reducibility of pores gets excluded categorically.

The fact is that there are many causes of pores in an aluminum weld. One of the main causes is hydrogen. This can come from various sources, such as for example hydrocarbons from grease. More frequently humidity can be seen as the source of hydrogen. Even this may come from different sources. Most of the sources like draft, condensation of humidity on the metal surface, condensation of humidity on the welding wire surface, air through leaks in the shielding gas supply system, etc. are well known to be sufficiently. Less known as a source for humidity, however, is the shielding gas hose.

2. MECHANISM OF PORE FORMATION DURING WELDING OF ALUMINUM

Depending on the mechanism of formation of the pores in the weld metal mechanical and metallurgical pores can be distinguished. As mechanical pores those are called that are based on the encapsulation of gases, by structural reasons. The present work deals with the formation of metallurgical pores.

Metallurgical pores are caused by the different solubility of gases in metals in the solid and liquid phase. During the transition from the liquid to the solid phase, the solved gases have to be deposited. This is also called degassing.

In the case of aluminum, hydrogen is regarded as the main cause of pores. The solubility of hydrogen in aluminum changes at the phase transition liquid / solid by leaps and bounds. During the solidification and the forming crystals the hydrogen gets deposited into the melt. The melt gets enriched further with hydrogen. If the degassing process until the end of solidification cannot be completed, a part of the hydrogen gets bound between the grains in the form of pores (Figure 1).

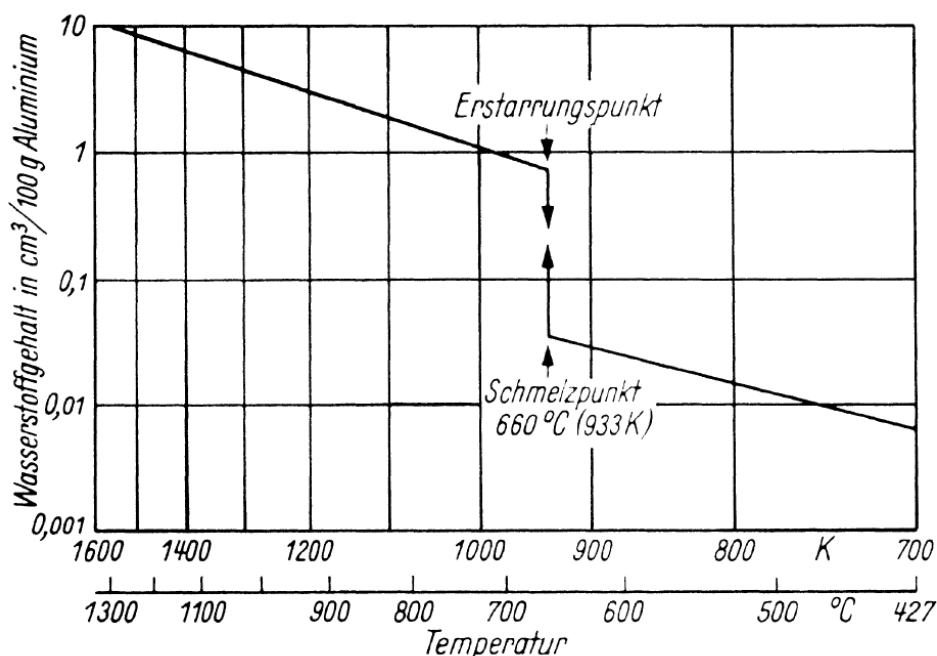


Figure 1. Solubility of Hydrogen in Aluminum

Since aluminum has a very high thermal conductivity, the solidification rate is relatively high. So that gas bubbles very often have no possibility to move up to the surface of the melt pool. They are surpassed by the solidification front and remain trapped as pores between the crystallites.

Depending on the solidification rate more or less gas bubbles are trapped. Pure aluminum has a solidification point. This causes the high tendency of aluminum to pore formation. In aluminum alloys we have a solidification interval. The greater the interval is, the longer the crystallization process is the lower is the tendency of the aluminum alloy to pore formation.

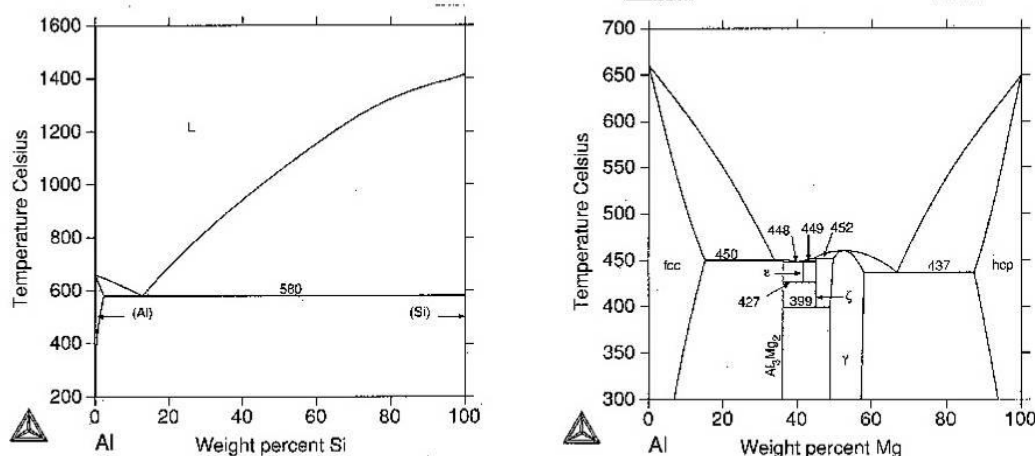


Figure 2. Phase diagrams AlSi and AlMg with big solidification interval

A well directed reduction of pores can be reached by using insensible base material or welding material. Never the less the general reduction of hydrogen or humidity in the direct welding area is more efficient.

Sources of hydrogen when welding aluminum by GMAW (gas metal arc welding):

- Oil and grease on the surface of the sheet
- Hydrogen containing aluminum sheets
- Hydrogen containing welding wire
- humidity

Sources of humidity:

- Oxide layers on the surface of welding wire or sheet
- Condense water on the surface of welding wire or sheet
- Air in the welding area by false torch position
- Air in the weld zone being injected by turbulences in the flow of shielding gas a by dirty gas nozzle
- Air in the welding area caused by leads of the torch
- Air in the welding area caused by the gas leading system
- hoses

Condensation occurs when the base metal or filler material is colder than the ambient temperature. Therefore, it is important to make sure that the base material gets allocated in the manufacturing facility early enough to reach room temperature before welding. Also the filler material should not be stored below the temperature of the workshop.

The following picture shows some of the possibilities of humidity absorption directly in the welding area.

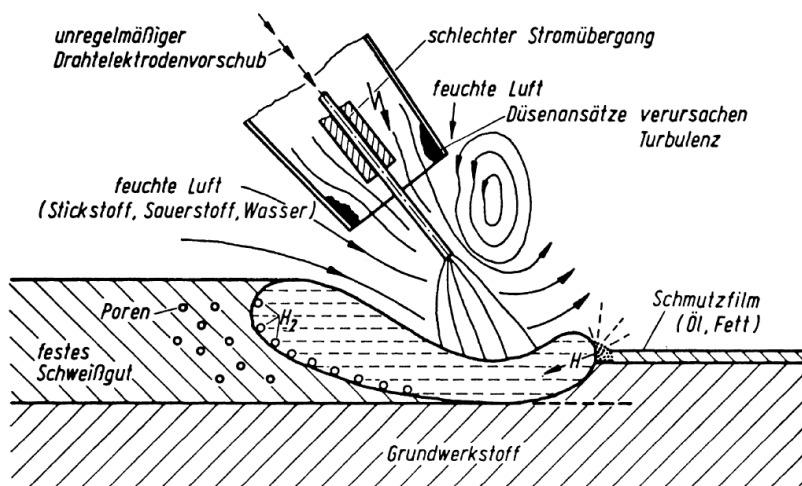


Figure 3. Possible sources of humidity in the welding area

3. HUMIDITY IN SHIELDING GASES BY HOSES

One of the above mentioned sources of humidity in the shielding gas are hoses. Plastics are known to be solving and transporting humidity. In this context we speak about:

- Absorption
- Diffusion
- Permeability
- Saturation
- Effusion

To describe the mechanism of how humidity gets absorbed and transported to the shielding gas by a hose we can use the terms permeability and saturation. Hereafter plastics can absorb humidity, up to certain saturation degree e.g., and transport the humidity to the shielding gas.

If and how much humidity gets absorbed or emitted depends on the supply of humidity and the saturation degree of the material.

In case of the shielding gas hose the situation is easy to describe. The air surrounding the hose contains about 50% - 60% relative humidity. That means 14.000ppm – 17.000ppm absolute. The shielding gas inside the hose contains about 5ppm absolute. The concentration gradient is very high and so the diffusion pressure is even high. The hose absorbing humidity from the air can easily transport the humidity to the shielding gas.

4. ESTIMATION OF THE RISK OF PORES FORMATION

As we now know that hydrogen is the main cause for pores when welding aluminum and the hose is a significant source of humidity there are two basic questions belonging to the relationship between humidity and pores:

1. How much humidity gets inserted by a hose system?
2. How much humidity can be accepted in the welding process?

To find out this relationship we had to make an examination based on practical tests. This meant at first to find out how much humidity and how long gets inserted to the welding process by different hose materials. To find the answer to question two we infected the shielding gas with humidity and examined at what concentration the first significant pores formation happened. As welding process we decided to use GMAW (gas metal arc welding) which is one of the most common welding processes for aluminum.

How much humidity gets inserted by a hose system?

To solve this question we tested different hoses made from different materials. The aim was to find out how much humidity gets transported from the hose material to the shielding gas and how long will it take to reach a clean shielding gas. All tested hoses had a length of 10 meters. We used commercial available hoses from a welding consumable shop. Before we started our tests all hoses have been stored in our laboratory. We had a room temperature of 23°C and the humidity accounted 35%, which was very low. The absolute humidity was about 10000 ppm. The purge flow of the shielding gas was 10 l/min. As shielding gas we used welding argon 99.996%.

The measurement of the moisture content inside the shielding gas at the end of the hoses was carried out by a suitable measuring device, which allowed the measurement in the ppm range.

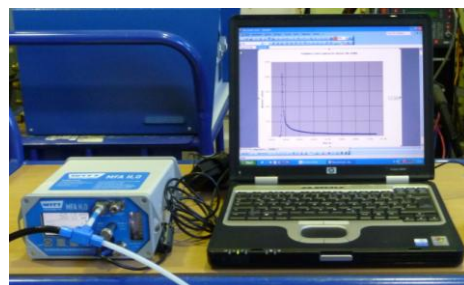


Figure 4. Measurement and documentation of purging time and humidity

Since PTFE is known to be particularly moisture resistant, we tested this material as a reference.

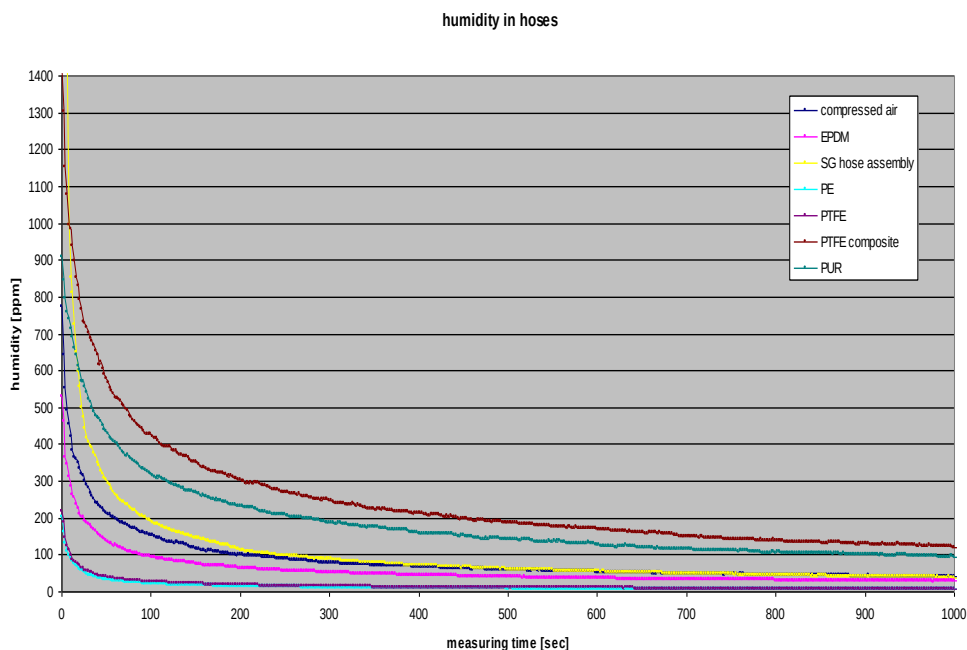


Figure 5. measurement of humidity, different hose materials

The graph shows that the saturation degree of each material is different. Once can see that the humidity concentration in the shielding gas is different at the beginning. The time which is needed to reach a constant concentration is different. The lowest level reachable depends on the different hose materials.

After starting welding the humidity content in the shielding gas after some minutes can amount up to some hundred ppm.

During purging the hoses the concentration of humidity decreases. The final result is that no kind of PVC hose is able to supply an acceptable shielding gas quality. The most expensive alternative is PTFE. The advantage of PTFE is the short purging time and the low level of humidity concentration that can be reached. One of the most important disadvantages is that PTFE is easy to bend and therefore not usable in a hose package. The results of PE were very satisfying but the low permeability also depends on different manufacturing parameters. That mean another hose from another producer may have other results.

View years ago a research project was started. The aim was to examine the permeability of hoses and the amount of humidity witch passes the different materials and takes effect to the welding process. The hoses were not really usable to produce hose packages for welding but the results of this project also approved these measurements.

How much humidity can be accepted in the welding process?

The literature gives two answers. McClure could detect the formation of pores at hydrogen concentrations up to 100ppm. In DIN EN ISO 14175 gases and gas mixtures are divided into different groups. For pure Argon 40ppm, for 2-component-mixtures 80ppm and for 3-component-mixtures 120ppm humidity are accepted.

These two answers are not very satisfying. To get a feeling for the relationship between humidity and pores we had to make an examination based on more practical tests. As welding process we decided to take GMAW. We wanted to find out the limit of moisture from which the

first pores formation can be detected. In our welding tests the shielding gas was systematically moistened with distilled water. Subsequently the shielding gas got fed directly into the welding torch by PTFE hoses to have no influence by the hose material. Immediately in front of the welding torch, the moisture content of the shielding gas was measured. Various moisture contents between 0ppm and 2000ppm were adjusted in the shielding gas for the different welding tests.

The measurement of the moisture content inside the shielding gas was carried out by a suitable measuring device, which allowed the measurement in the ppm range. To ensure the accuracy of the humidity content the measurement was made immediately in front of the welding torch.



Figure 6. Supply of shielding gas and point of measurement

The welding specimens were welded by using a mechanized welding process. This allowed 100% reproducibility. To exclude effects caused by gap preparation melt runs were welded.

Figure 6 shows the direct shielding gas supply to the torch and the hose connection for the humidity measurement can be seen.

As ground material one the most common aluminum alloy was selected. AlMg3 is one of these alloys and is characterized by a good weldability. As welding wire we used AlMg 4,5 Mn.

With increasing moisture in the shielding gas an increasing formation of micro pores (Figure 7) can be detected. This kind of small and regular spread pores is typical for GMAW (gas metal arc welding). On the radiographs the pores are not easy to detect.

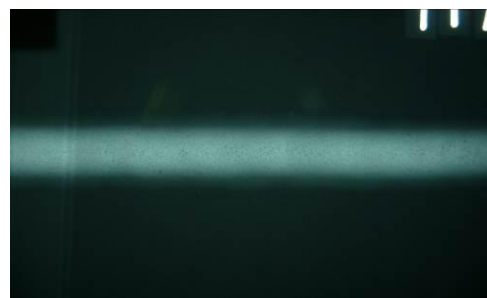


Figure 7. Micro pores at 1900ppm

To make the pores visible micro sections were prepared. Now the influence of the humidity was visible (Figure 8).

The evaluation and ranking of pore-size and frequency was made in accordance with DIN EN ISO 10042. Here pore-sizes and frequencies will be divided into groups. Due to the size the pores are easy to overlook.

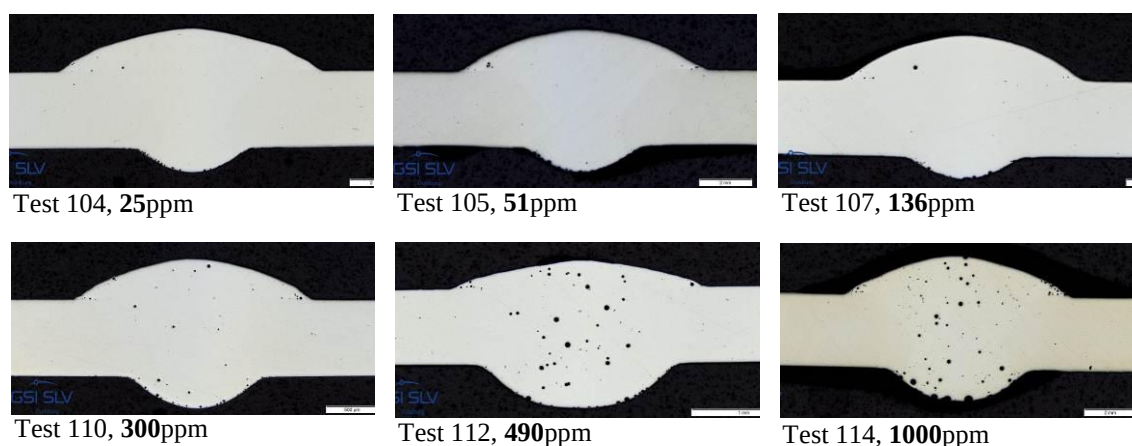


Figure 8. Micro sections with micro pores

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The most popular shielding gas mixtures consist of argon and helium. At first the different shielding gases show the well-known advantages. With raising amounts of helium the seams get smoother and have a better penetration.

In addition to these facts, an influence on the formation of pores was observed.

When evaluating the radiographs the first "change of seam design" was documented. The evaluation had the following results:

Shielding gas		radiographs	micro sections
• Argon 4.6	from about	490 ppm	300 ppm
• Aluline He30	from about	800 ppm	600 ppm
• Aluline He50	from about	1250 ppm	1000 ppm

The limits above showed the first visible change of the design of the seams compared with the micro sections. With further increase of moisture content the amount of pores get more and more and the visibility of the micro pores raises.

6. REDUCING OF THE FORMATION OF PORES WHEN WELDING ALUMINUM

To reduce pores in a well-directed way when welding aluminum it is necessary to prevent to every possible source of hydrogen or humidity. So take care of:

- Preparing the base material directly before welding
- Pay attention to the temperature of the base material
- Store the welding wire warm, dry and covered
- Opened wire should be used as soon as possible
- Leak test of welding plant and equipment from time to time
- Remove spatters from gas nozzle (turbulent gas stream)
- Leak test of gas supply system

The gas supply system especially is very sensible. It begins with the pressure regulator an ends at the gas nozzle. The following parts have to be inspected regularly:

1. pressure regulator – tightness
2. hose connector at the pressure regulator – tightness
3. hose between cylinder and welding plant – tightness, porosity, material
4. hose connector at the welding plant – tightness
5. hoses inside the welding plant (if possible) – tightness, porosity, material
6. hose inside the hose assembly – tightness, porosity, material
7. torch and gas nozzle – tightness
8. wire feeder – tightness
9. wire nozzle and wire guide tube – correct size

Even small leaks can lead to a huge increase in air and thus also of humidity in the shielding gas. Even low porosities at shielding gas hoses lead to an intake of air. It is often mistakenly assumed that wherever there's a gas leak no air could penetrate. This assumption is wrong. Therefore it is advisable to change old hoses. This saves money, time and trouble.

If the welding process still produces pores it is possible to use gas mixtures based on argon and containing helium between 30% and 50%.

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