STREICHER Group

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HYDROGEN GOES PUBLIC

Hydrogen is not just a raw material, but is increasingly developing into an energy source for the masses.

What are the resulting requirements for materials, welding and testing.

History

Water is the coal of the future

Tomorrow's energy is water that has been broken down by electricity.

The elements of water broken down in this way, hydrogen and oxygen, will secure the earth's energy supply for the unforeseeable future.

Jules Verne, The Mysterious Island, 1875

Hydogen an old Friend

Hydrogen as a raw material

Hydrogen is an important raw material for the synthesis of chemical compounds and in reduction reactions in metallurgy.

Industry uses hydrogen for decades.

- In oil refining
- Production of fertilizers
- Production of methanol as a raw material for high-quality chemical products
- Production of steel

Hydogen an old Friend

Hydrogen is the most abundant chemical element in the universe.

A kilogram of hydrogen contains about 2.4 times as much energy as natural gas.

Hydrogen lines can achieve an energy transport capacity that is 8 to 10 times higher than that of power lines.

Legal Guidelines

The basis is the Paris Agreement of the year 2015.

Its overarching goal is to hold the increase in the global average temperature below 2 ^{0}C above pre-industrial levels.

In order to achieve the long-term temperature goal, parties aim to reach global peaking of greenhouse gas emissions as soon as possible.

National and international decarbonization requirements will require a CO2-neutral energy supply in the future.

Storage and Transport of renewable Energy

Today we are faced with the challenge of storing and transporting energy from renewable sources such as wind and sun, which are not constantly and evenly available.

Transport can be direct, via power lines.

Storage can be done directly in batteries.

Transport and storage of electric power is very expensive and requires the creation of new, extensive infrastructure.

There are also some industrial processes that cannot be electrified, or only with difficulty, such as steel production or chemicals production.

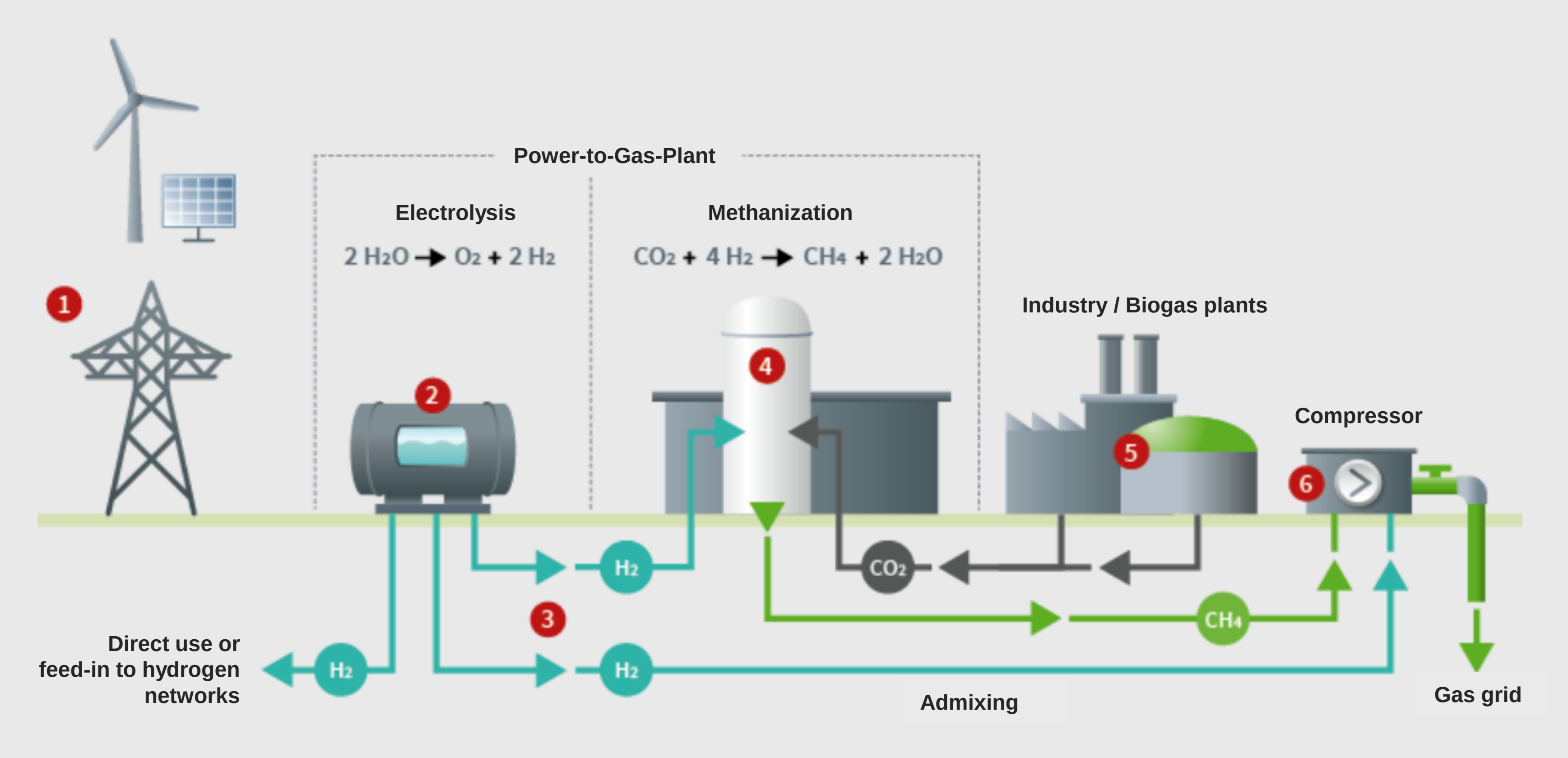
That's why we need other solutions to transport, store and use the energy generated in this way.

One of these solutions is hydrogen.

Hydrogen Generation

Until now most of Hydrogen is produced from light Hydrocarbons, e.g. Natural Gas Reforming

Production of Hydrogen from renewable energy



Hazards from handling Hydrogen

Why we are afraid of hydrogen?

Maybe it is in the past

- Oxyhydrogen Test in Chemistry Class
- The fire on board of the airship Hindenburg is still often cited as an example of the explosion hazard of hydrogen.
  However, it has long been proven that there was no explosion at all and that the accident was not caused by hydrogen, but by an electrostatic spark that ignited the airship's combustible coating.

According to its physical and chemical properties, hydrogen is not more dangerous than conventional energy sources such as natural gas or petroleum.

There is a long tradition of using hydrogen in the public sector.

City gas has been used since the end of the 19th century.

City gas consists of approx. 50% hydrogen.

Nevertheless, high safety standards must apply when handling hydrogen, as there is a risk of explosions or hydrogen embrittlement.

Effect of Hydrogen on Materials

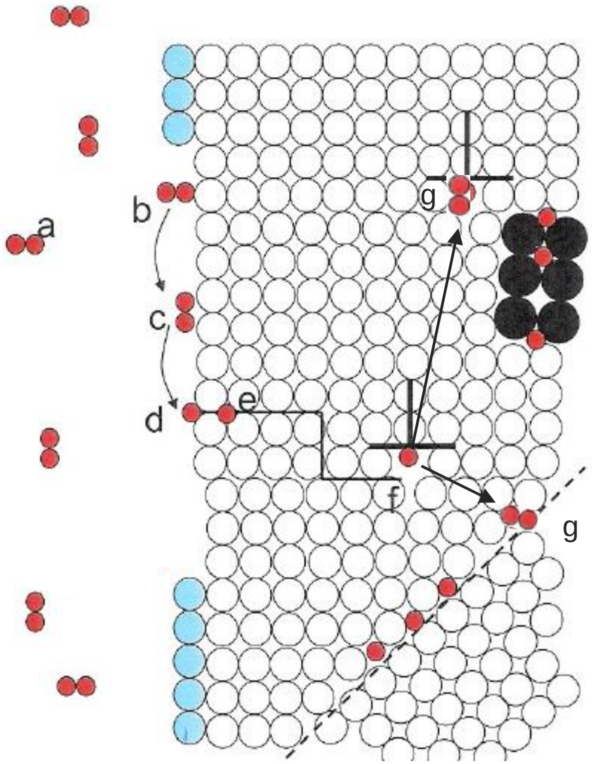
Dissolved hydrogen leads to embrittlement phenomena in iron or low-alloy steel,
i.e. toughness, deformability or fatigue strength are reduced.

The various damage processes caused by hydrogen are generally referred to as hydrogen embrittlement (HE).

If mechanical tensile stress is applied, hydrogen-induced stress corrosion cracking (HSCC) can occur.

Materials with high strength and zones with strong local mechanical stress (notches) are very susceptible to HE.

Hydrogen Embrittlement Process



a–b: Molecular Adsorption

b-c: Chemisorption of the molecule

c-d: Dissociation

d-e: Solution in the matrix (absorption)

e-f: Diffusion of Atoms to "traps"
(matrix defects, phase boundaries)

f-g: Recombination
(bulking, tension and stress increase in the matrix)

Factors influencing Hydrogen Embrittlement

Generally speaking, at temperatures below 200 ^{o}C, the hydrogen activity is too low to be adsorbed on the surface and subsequently absorbed.

The same applies to partial pressures below 100 bar, where the hydrogen activity is also too low to be adsorbed on the surface and then absorbed.

However, if the material is subjected to mechanical stress, such as at notches, low pressures and low temperatures are often sufficient to cause the hydrogen to adhere to the face.

This is especially the case for high-strength steel.

Materials and Hydrogen Embrittlement

Low alloy steels are susceptible to hydrogen embrittlement.

Steel manufacturers have observed a negative influence of hydrogen in tests, especially for higher-strength grades.

Austenitic corrosion resistant stainless steels are resistant to hydrogen.
Especially stainless steels with reduced carbon content, e.g. 304L, 316L.

Polymeric materials are not affected.
Although hydrogen diffuses into or through such materials, there is no damage or other change in the mechanical or chemical properties.

Materials

EUROPEAN INDUSTRIAL GASES ASSOCIATION (EIGA IGC Doc 121/14) Guideline

Various carbon steel specifications for pipelines are listed in Appendix C.

When choosing the material, the following criteria should be taken into account:

- Avoidance of hard or high strength alloys.
- Free from significant surface defects such as scratches, notches, carbon deposits, corrosion.
- Maximum Carbon Equivalent (CE) is 0,43.

Materials

EIGA Guideline

Recommended Materials:

Carbon Steels

- Low strength alloys are preferred >>> If they fail, they usually fail ductil.
- Higher strength alloys with homogenous quenched and tempered fine-grained microstructure are more resistant to hydrogen cracking than the normalized.
- A maximum tensile strength of 800 Mpa is recommended.

but

- Appendix C list API 5L X52 as highest strength grade prooven.

Materials

EIGA Guideline

Recommended Materials:

Stainless Steels

- Austenitic stainless steels have excellent resistance.
    - ➢ Metastable austenite (grades 201, 301, 302, 304, 321) can get susceptible to hydrogen when higher strained, particularly, at lower temperatures.
    - ➢ For high pressure, stainless steels with high austenite stability are to be prefered (316, 316L)

Materials

ASME B31.12 – Hydrogen Piping and Pipelines

Approved Materials for **Industrial Piping**:

Listed in

Table GR-2.1.1-1 Material Specification Index for Piping and Pipe Components

Approved Materials for **Pipelines**:

Listed in

Table GR-2.1.1-2 Material Specification Index for Pipelines

ASME B31.12 does explicitly allow the use of grades up to X80 for hydrogen service.

but

The non-mandatory Appendix A of ASME B31.12 indicates that only grades up to X52 are proven for service in hydrogen.

Materials

Welding Filler Metal

The nominal tensile strength of the weld metal shall be equal or higher than the tensile strength of the base metal.

For base metals of different tensile strength, the nominal tensile strength of weld metal shall be equal or higher than the tensile strength of the weaker of the two.

The nominal chemical analysis of the weld metal shall be similar to the chemical analysis of the base material.

If materials of different chemical analysis are joined, the weld metal shall be similar to one of the base metals or shall have an intermediate composition.

When austenitic steel is joined to ferritic steel, the weld metal shall have austenitic structure.

Welding

General Welding Requirements

EIGA Guideline

All pipe welding shall be performed in accordance with welding procedures qualified to the specified code.

All welders employed must be qualified to the procedures in accordance with the specified piping code.

Welding processes and operators qualification should verify that weld sample meet the same strength and toughness requirement as the parent metal.

Hydrogen touched surface of weld should be free of defects such as scratches, notches, carbon deposits, and corrosion.

Heat affected zones should match the mechanical and toughness properties of the joined materials.

For austenitic stainless steel, the ferrite content in the welding zone should be limited to 7%.

Welding

EIGA Guideline

Accepted Welding Processes:

- GTAW
- SMAW
- GMAW (automatic)
- GMAW (manual) for shop pre-fabrication of piping

Welding

ASME B31.12

General Welding Requirements

PQR Requirements

- Base metal shall be made from the same specification (same P-Number and Group Number) as piping.

- Base metal shall be similar in chemistry as piping.

- Base metal shall be in the same heat treating condition as piping.

- Thickness of test coupons shall not be less then the piping.

Welding

ASME B31.12

Accepted Welding Processes

Manual Welding

- SMAW
- GTAW

Semiautomatic Welding

- GMAW
- FCAW

Mechanized Welding with Filler Metal

- GTAW
- GMAW
- FCAW
- PAW
- SAW

Mechanized Welding without Filler Metal

- GTAW
- PAW

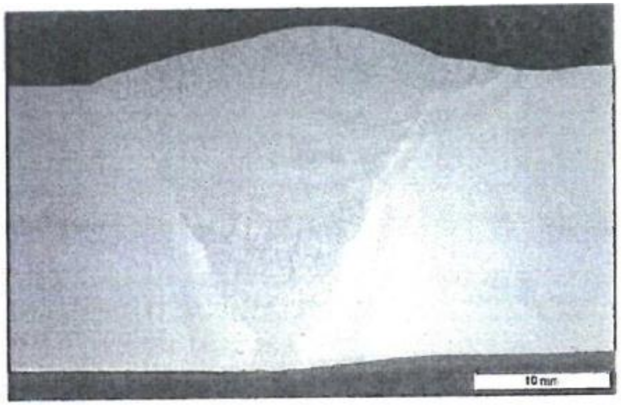
Qualified Welding Processes

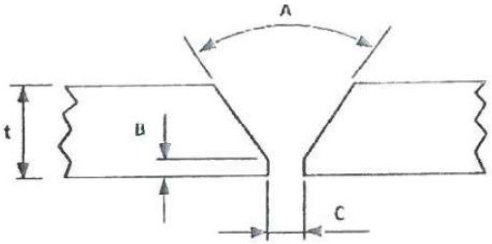
Pipeline Welding Processes for Hydrogen Use

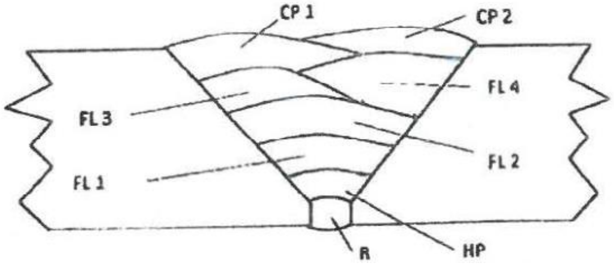
Material: L485 / X70

Dia: ≥ 406 mm
Wall Thickness: 11 - 44 mm

Welding Process: 135 (automated) – G 46 3 C1 4Si1
136 (automated) – T 55 5 Mn1Ni P M 2 H5







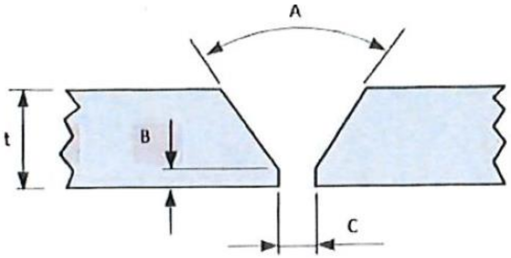
Qualified Welding Processes

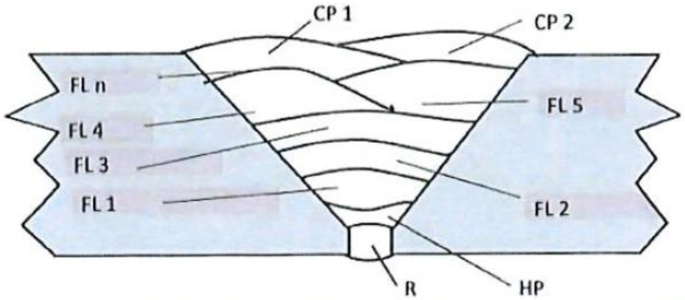
Pipeline Welding Processes for Hydrogen Use

Material: L485 / X70

Dia: ≥ 30 mm
Wall Thickness: 3 - 80 mm

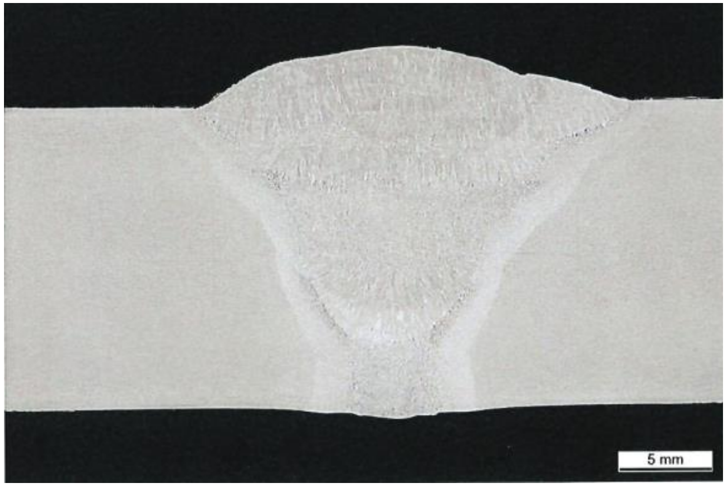
Welding Process: 141 – W 46 3 W2Mo
111 – E 55 6 1NiMo B 4 2 H5





Qualified Welding Processes

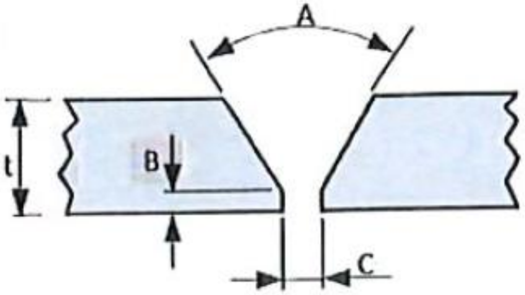
Pipeline Welding Processes for Hydrogen Use

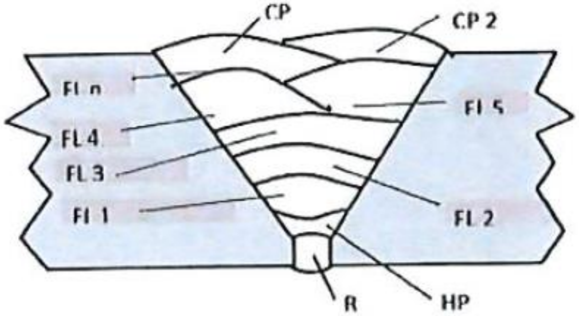


Material: L485 / X70

Dia: ≥ 84,2 mm
Wall Thickness: 3 – 56,4 mm

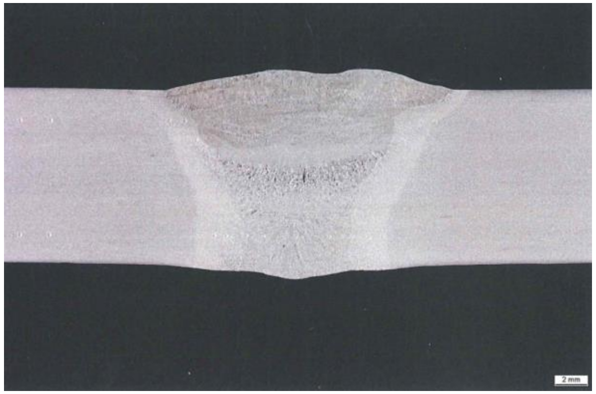
Welding Process: 111 – E 55 6 1NiMo B 4 2 H5





Qualified Welding Processes

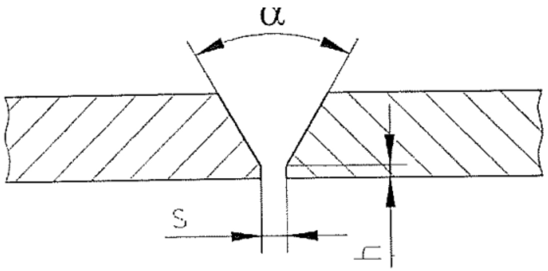
Pipeline Welding Processes for Hydrogen Use

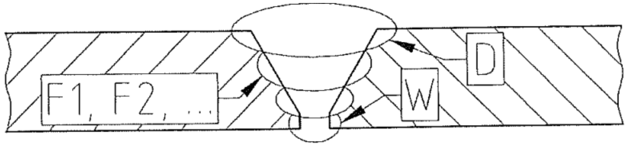


Material: L485 / X70

Dia: ≥ 25
Wall Thickness: 3 - 44 mm

Welding Process: 141 – W 46 3 W2Mo





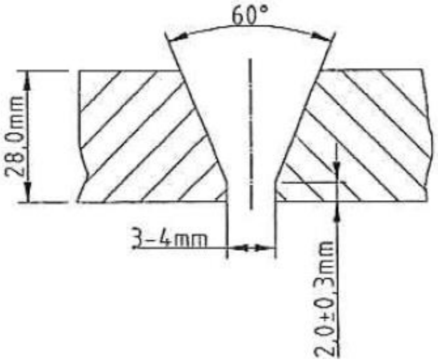
Qualified Welding Processes

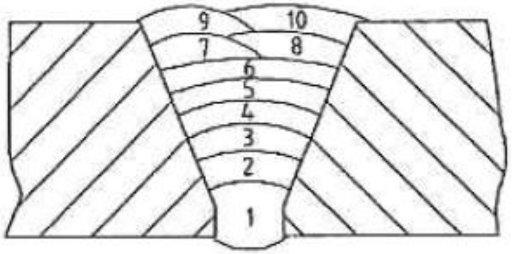
Pipeline Welding Processes for Hydrogen Use

Material: L485 / X70

Dia: ≥ 510
Wall Thickness: 14 - 56 mm

Welding Process: 141 – W 46 3 W2Mo
136 (automated) – T42 4 P M 1 H5





Mechanical Properties

Hardness

It is important that hardness levels in the weld and weld heat affected zone be controlled to avoid hard spots.

Hardness Values for Welds and HAZ

Directive / Standard		Base Material	Hardness Values [HV]
ASME B31.12	Part GR Procedure Qualification	P1 P3 P4 P5A / P5B	235 235 235 248
	Part IP Industrial Piping	P1 P3 P4 P5A / P5B	200 225 225 241
	Part PL Pipelines	P1 (non PWHT) CS (SAW or FCAW welded) Weldments with CS filler metal containing min. 1,6% Mn Any PWHT weldment	249
EIGA		All	248

Individual Quality Requirements

The main challenge is that the existing natural gas pipeline infrastructure and no special hydrogen pipelines should initially be used for hydrogen transport.

Therefore, an individual consideration and own experiences or the consultation of an experienced expert are essential in order to specifically exclude hydrogen embrittlement and other risks.

Weld filler metals, weld process qualification, weld operator qualification, mechanical tests, metallographic techniques and NDE techniques all play a role in ensuring that the fabricated pipeline has adequate toughness for hydrogen applications.

Thank you for your attention.

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