EIGA TECHNICAL BULLETIN

Prepared by WG-2

TB 42/22 – March 2022

Welded Gaseous Storage Vessels and Hydrogen Compatibility

1. Introduction

This Technical Bulletin reflects Appendix 5, which was removed from EIGA Doc 15/21 [1]. The recommendations are kept concerning the suitability of welded gaseous storage for hydrogen service and provides guidelines for minimising the effects of embrittlement when designing new welded storage vessels and gives recommendations for assessing the safety of existing storage vessels, when the design pressure is greater than 25 bar.

The two most important factors in ambient temperature hydrogen embrittlement are the purity of the hydrogen, and to a lesser extent the hydrogen pressure.

In determining a critical value for oxygen impurity, the literature is somewhat variable. However, generally the hydrogen embrittlement effect is maximised when the oxygen impurity is less than 10 ppm/V but decreases with increasing impurity to the extent that oxygen levels above 200/300 ppm/V completely inhibit the hydrogen embrittlement effect. As with impurity, opinions vary as to what is a critical pressure. Generally, for carbon steels below 10 bar, the effect of hydrogen in causing ambient temperature embrittlement is minimal, while hydrogen pressures above 25 bar have a progressively greater effect.

There are three possible mechanisms that could be responsible for the initiation and propagation of a defect, causing welded hydrogen vessels to fail:

a. The presence of critical surface defects resulting from manufacture or previous service. Such defects may then be subjected to hydrogen assisted crack propagation under the normal influence of the vessel filling cycles.

b. The initiation and propagation of the hydrogen assisted fatigue cracks due to very high additional local stresses.

c. The use of a material and/or weld deposit that is highly susceptible to hydrogen embrittlement.

2. Guidelines for the design of hydrogen storage vessels

Vessels for the storage of hydrogen shall be designed, fabricated and inspected in accordance with a recognised pressure vessel code and the following requirements:

2.1 Materials

2.1.1 The actual yield strength of the material shall be no greater than 420 MPa.

2.1.2 The actual tensile strength of the material, shall be no greater than 630 MPa.

2.1.3 The material shall be in the normalised condition.

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2.1.4 The material shall have specified values for toughness at -20°C. according to the pressure vessel code.

2.1.5 The carbon equivalent shall conform to the following requirement

$$Ceq = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{Ni + Cu}{15} < 0.45$$

2.2 Design and Construction

2.2.1 A fatigue analysis based upon the design cyclic duty should be performed. The analysis should include the effects of hydrogen which are reported in the literature.

2.2.2 Local stress raisers shall be minimised by:

a. Appropriate design and positioning of nozzles, manholes, supports and attachments and the selection of suitable weld details. Penetration welds are preferred.

b. Ensuring welds have uniform profiles that are well blended into the surface of the parent plate and free of undercut or over reinforcement.

c. Avoiding gouges, scrapes, grinding marks and weld splatter during manufacture. The maximum depth of the defect shall not exceed 5% of the wall thickness.

d. Employing plate rolling techniques that minimise peaking. (Peaking is a deviation from the truly circular shape that occurs at welds due to an inability to roll to the plate edge. The allowable peaking depends on the diameter of the vessel, see Fig. 1 and 2).

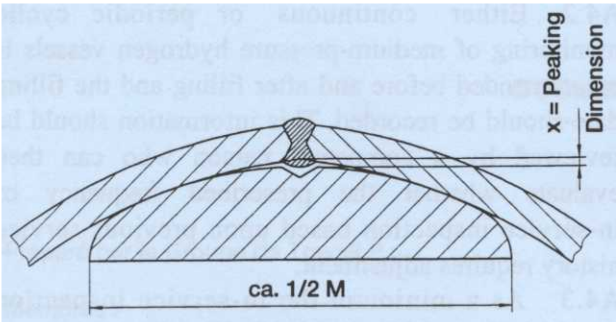

Figure 1 – Internal template

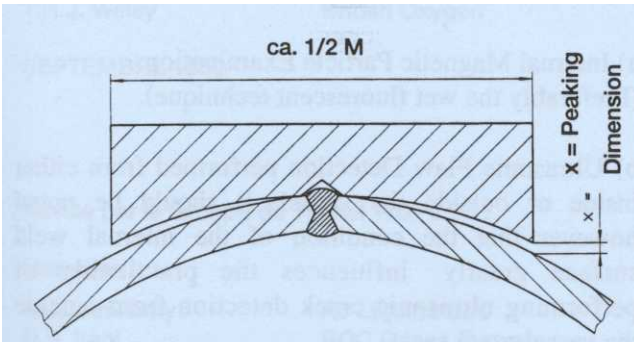

Figure 2 – External template

For commonly used vessels with a diameter of approximately 3 metres the peaking should be less than 4 mm (*).

* 4 mm represents the value in the AD-Merkblätter in Germany

2.2.3 All welds shall be subject to 100% non-destructive testing.

2.2.4 The hardness of welds and the heat-affected zone shall be less than 250 HV

2.2.5 The inside and outside surface conditions of all main seam welds should be prepared to a standard suitable for either ultrasonic testing or magnetic particle inspection.

2.2.6 The vessel should be protected by suitable overpressure protection adequately sized for all foreseeable events, including an uncontrolled gas release from a filling trailer. Both the position of the overpressure protection with respect to the vessel and the sizes of connecting lines shall be taken into account when designing the protection system.

3. Recommendations for assessing of existing hydrogen storage vessels

3.1 For each vessel in operation perform the following

3.1.1 Obtain the following operational data as available either from records or by estimation

- Technical and material data according to national design codes and/or company specification.
- Previous results of periodic testing
- Storage vessel cyclic duty history for number of filling cycles and magnitude of service pressure range.

3.1.2 Review of pressure vessel construction and design in particular to determine local stress raisers.

3.1.3 Using data from the literature perform a fatigue analysis taking account of the effects of hydrogen, the local stress situation and where practical the material susceptibility to embrittlement based upon hardness.

3.1.4 Review the results of the fatigue analysis and the collated technical material and historical operating data and determine whether the vessel falls within one of the following categories;

- A vessel with special findings of abnormalities during periodic inspections in the past.
- A vessel with high number of filling cycles and a significant pressure range (greater than 65% of the max. working pressure).
- A vessel with unsuitable design features, which cause unacceptable local stresses, e.g. flanges, manholes in the cylindrical part, compensation pads other welded attachments or reinforcements on the pressure vessel.
- A vessel that does not meet the material requirements according to clause 2.
- The accumulated fatigue cycles are greater than half the allowable design cycles following from a fatigue analysis according to clause 3.1.3.

3.1.5 For those vessels falling within the categories listed in 3.1.4 above, perform non-destructive testing of the main seams and any other identified suspect areas by an appropriate method. Some acceptable non-destructive testing techniques are specified in 4.3.

Also measure the deviation in geometrical shape in the vicinity of the longitudinal main seams. Differentiate between ovality and peaking and determine the local stresses due to each type of deviation. (Note 1)

Note 1 - In Germany peaking measurements were performed on all existing vessels following a FAD instruction. It is EIGA's prevailing opinion that this is only necessary when one of the conditions in 3.1.4 applies.

3.1.6 Dependent on the failure analysis and the results of the non-destructive testing the suitability of the hydrogen storage vessel for further operation can be determined as follows:

- Without any restrictions
- With reduced service pressure or pressure range
- With decreased retest periods
- With reduced number of pressure cycles
- Unsuitable for further service

4. In service Inspection and Cyclic Monitoring

4.1 As recommended in 4.3, medium-pressure hydrogen storage vessels should be subjected to periodic in-service inspections. The frequency of these inspections should be determined by the cyclic duty of the vessels when compared to the design cyclic life and the periodic inspection requirements of the national regulatory authorities.

4.2 Either continuous or periodic cyclic monitoring of medium-pressure hydrogen vessels is recommended before and after filling and the filling date should be recorded. This information should be reviewed by a competent person who can then evaluate whether the prescribed frequency of in-service inspection based upon previous service history requires adjustment.

4.3 As a minimum the in-service inspection should include 100% NDT of all main weld seams by an appropriate method capable of ensuring that all small internal surface cracks typically 3 mm long by 1 mm deep, will be detected. Such methods are:

a. Internal Magnetic Particle Examination. (Preferably the wet fluorescent technique).

b. Ultrasonic Flaw Detection performed from either inside or outside the vessel. It should be noted however that the condition of the internal weld surface greatly influences the practicality of performing ultrasonic crack detection from outside the vessel.

c. Pressure testing in conjunction with Acoustic Emission. All local acoustic activity will require evaluation by (a) or (b) above.

4.4 The term weld seam shall be taken to mean the weld seam itself plus the heat affected zone. Typically, a band 50 mm wide will suffice.

5. References

EIGA Doc 15 *Gaseous Hydrogen Installations* www.eiga.eu

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