Dear Annett

Luxfer Gas Cylinders would like to provide feedback with regards to Annex 8 – Part 2: Humid Gas Stress Corrosion Cracking Test, of the "Proposal for the 02 Series of Amendments to UN Regulation No. 134 – Consolidated Text on the Safety-Related Performance of Hydrogen-Fuelled Vehicles"

1. **As Luxfer Gas Cylinders have stated previously SAFETY is paramount!**
2. **Please see below feedback from Henry Holroyd, sent to Annett Scheussling, 28th January, in response to the feedback received from Japan on his presentation with regards to the proposed Humid Gas SCC Test**
    a. *Many thanks for your e-mail sending me a copy of the Japanese response.*
    b. *We have no issues with the quality of excellent data provided by the Japanese experts.*
    c. *The critical flaw in their argument presented to rebuff Luxfer's position is the material used in their demonstration 'good' AA6061 material will pass their proposed test has not been taken from commercial AA6061 cylinders or liners.*
    d. *It is not a surprise that the AA6061 material used by the Japanese can pass their proposed test.*
    e. *A different test result will be obtained when test samples are extracted from commercial AA6061 cylinders or liners manufactured, even when using 'good' AA6061 material.*
    f. *The alloy microstructure of the AA6061 material used by the Japanese Experts is not representative of that for commercial high pressure gas cylinders or liners, which will differ significantly, reflecting differences between the thermo-mechanical processing involved.*
    g. *Luxfer Gas Cylinders needs some time to generate the experimental evidence to justify their claims.*
3. **Additional thoughts, subsequent to the January email, from Henry Holroyd are provided below:**
    a. The Humid-gas SCC test is 100% based on the ISO SLC test method, which originated and evolved from research conducted in the UK at Alcan International Ltd. As such, it is being proposed that this test method is being proposed to determine the potential susceptibility to a different sub-critical cracking mechanism (SCC as opposed to SLC), which necessitates the use of a different pass/fail criteria. Both the SLC and the SCC tests have a pass criterion of <160 µm of cracking.
        i. An analogous situation is the case of 'cyclic', as opposed to 'static' loading, for example, during cyclic pressurization test, is it reasonable to demand the same minimum number of loading cycles-to-failure for tests conducted in 'dry air', as in 90% relative Humidity.
        ii. For the proposed Japanese Humid-gas SCC test a pass/fail crack growth of 1000µm, would be more appropriate.

4. **Additional questions and comments with regards to the Proposed Humid Gas Stress Corrosion Cracking Test**

    a. Test data

        i. Has any testing been carried out, using the proposed test methodology on actual material taken from Type 1, Type 2 and Type 3 gas cylinders?
            1. If Yes:
                a. Which CPs have carried out such testing?
                b. Where were the cylinder/liner material test samples taken from?
                c. What were the size and orientation of the test samples?
                d. Are the test results available for review?
            2. If No:
                a. It is strongly recommended that such testing is carried out on cylinder and liner material.

    b. Test Protocol

        i. Humidity requirements
            1. The specification for hydrogen has a maximum water content of ≤ 5 µmol/mol
                a. Hydrogen gas shall be compliant with ISO 14687:2019, SAE J2719_202003, or meet the following specifications:
                    i. Hydrogen fuel index: ≥ 99.97 per cent;
                    ii. Total non-hydrogen gases: ≤ 300 µmol/mol;
                    iii. **Water: ≤ 5 µmol/mol;**
                    iv. Particle concentrations: ≤ 1 mg/kg.

            2. A wide range of AA6061 pressure receptacles, manufactured by Luxfer Gas Cylinders, have been successfully used in CNG applications for many years e.g. for transport and mobility. It should be further noted that both Dry and Wet gas are called out in ISO 11439: Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles. The definitions of dry and wet gas are provided below:

                a. 4.5.2 Dry gas
                    i. **Water vapour shall be limited to less than 32 mg/m3** (i.e. a pressure dewpoint of –9 °C at 200 bar).
                    ii. Constituent maximum limits shall be:
                        1. Hydrogen sulfide and other soluble sulfides 23 mg/m3
                        2. Oxygen 1 % (volume fraction)
                        3. Hydrogen, when cylinders are manufactured from a steel with an ultimate tensile strength exceeding 950 MPa, 2 % (volume fraction)

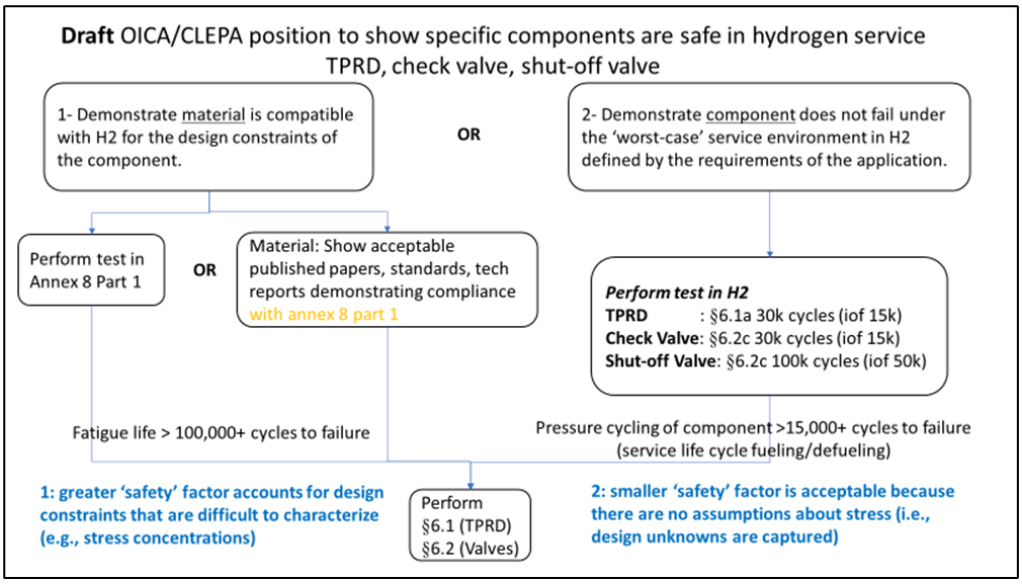
b. 4.5.3 Wet gas
    i. **For gas that has a higher water content than that of dry gas**, constituent limits shall be:
        1. Hydrogen sulfide and other soluble sulfides 23 mg/m3 maximum
        2. Oxygen 1 % (volume fraction) maximum
        3. Carbon dioxide 3 % (volume fraction) maximum
        4. Hydrogen 0,1 % (volume fraction) maximum

c. Pass/Fail criteria
    i. A small amount of cracking is permitted within the test i.e. less than 160µm. However, such small amounts of cracking can be introduced during the loading of samples. Thus, it may be appropriate to increase the permitted crack length during test, to say 0.5 mm.(500 microns)

5. Supporting information

a. Material compatibility requirements in today's legislation
    i. Compressed Hydrogen cylinders have been used and transported for many many years. During that time standards and specifications have been developed and these are referenced in International Regulations e.g.
        1. Recommendations on the TRANSPORT OF DANGEROUS GOODS Model Regulations, Twenty-second revised edition, UN Model Regulations
            a. Two standards are referenced in the Regulations – see below:
                i. ISO 11114: Gas cylinders - Compatibility of cylinder and valve materials with gas contents (including Hydrogen)
                    1. Part 1: Metallic materials
                    2. Part 2: Non-metallic materials
        2. Note that these standards are also called out in: ECE – Inland Transport Committee: ADR – Agreement concerning the International Carriage of Goods by Road (note that RID and ADN, also exist for the Carriage of Goods by Rail and Waterways respectively), applicable from 1st January 2023

b. Draft OICA/CLEPA position to show specific components are safe in hydrogen service TPRD, check valve, shut-off valve



i. Should the OICA/CLEPA position (shown above), providing an alternative approval route for the safe use of components in hydrogen service i.e. TPRD, check valve, shut-off valve, be considered as an alternative route for pressure receptacles? Such approval routes would negate the need to conduct testing, on wrought aluminium alloys, in accordance with Annex 8: Part 2.

6. In summary

a. If the proposed Humid-gas SCC test is accepted as written it is likely that this test will disallow cylinder materials, which have been successfully used, in hydrogen applications, for many years?

b. It would be appropriate for discussions to be held between Experts and for experimental studies to be carried out using cylinder materials. Note that Experts could also be drawn from outside of the Task Force, for example:

i. Industry Associations
   1. EIGA: European Industrial Gases Association
   2. JIMGA: Japanese Industrial and Medical Gases Association
   3. ECMA: European Cylinder Makers Association
   4. CGA: Compressed Gas Association (Canada and USA)

ii. International committees
   1. ISO/TC 197: Hydrogen
   2. ISO/TC 58: Gas Cylinders
   3. CEN/TC 23: Gas Cylinders

It would be very much appreciated if the above information could be taken into consideration prior to any decision being taken on the inclusion of Annex 8 – Part 2: Humid gas stress corrosion cracking test, into UN Regulation No. 134 – Consolidated Text on the Safety-Related Performance of Hydrogen-Fuelled Vehicles.

Yours sincerely