THE USE OF AUSTENITIC STAINLESS STEEL PIPE FOR CARRYING HYDROGEN GAS.

Introduction

Austenitic stainless steel is used for the transport of hydrogen gas on the ------- site. As part of the ------------------, the safety of the pipelines carrying various fluids at ambient temperature was reviewed - this included hydrogen gas.

Current Design Manual

This recommends the use of 304L grade stainless steel for the transport of hydrogen gas but does not offer any substantiation for this. This was based on the fact that this has been standard practice for many years at --------- with no reports of any problems.

References

Reference to standard textbooks (e.g. Ref 1) suggests that there is a possible embrittlement problem where hydrogen gas is used at high pressure. Therefore the original references from the text books have been examined as follows:

Ref 2.

This examined 35 alloys for their susceptibility to embrittlement in high pressure hydrogen environments but only the austenitic stainless steel data are reviewed here. Many of the tests involved carrying out tensile tests in high pressure hydrogen but one phase of the work looked at the effect of holding a specimen in hydrogen and then testing. This is closer to the situation in pipelines. The investigation involved only one austenitic stainless steel – grade 310 – and the maximum exposure time was 24 hours. The results showed that there was no effect on the tensile properties after the exposure to hydrogen. Care must be taken not to read too much into this result since 310 is a much more stable alloy than 304L. Other tests in the programme where these alloys were tested in high pressure hydrogen showed that 304L was much more effected than the 310 stainless steel. This was attributed to the stability of the alloy.

Ref 3

This refers to testing of samples deliberately charged with hydrogen and is therefore not considered relevant.

Ref 4

This showed a reduction in elongation from 60% to 30% for 304L stored at 202 deg C in 10,000 psi hydrogen for two months (grade 309S did not show a similar loss). This reduction is not considered serious for a hydrogen pipeline since 30% is still a significant amount of ductility and can hardly be classed as brittle. Also the test conditions are more extreme than the situation of pipes at ------- (ambient temperatures and lower pressures). There is also the fact that a pipe can have hydrogen diffusing in from one surface and out through the other whereas in the laboratory tests hydrogen is charged into the samples from both surfaces and not allowed to escape.

However, when the original source paper was examined it was found that the tensile properties of the stainless steel were only affected when the tensile tests themselves were carried out in a hydrogen atmosphere. When such tests are carried out there is a marked reduction in tensile strength and ductility at room temperature. Grade 304L stainless steel specimens were tested in tension in hydrogen pressures between 2,500 and 10,000psi at room temperature and all showed some reduction in tensile properties. This was attributed to the formation of martensite during the deformation of the tensile specimen. A grade 310 stainless steel which did not form martensite during deformation did not show any loss in tensile properties.

This also raised the possibility that if deformation induced martensite were present in a specimen which was then subsequently exposed to hydrogen at high pressure from deformation, then embrittlement could occur. The researchers checked for this possibility but found no reduction in tensile properties.

Conclusion

The lack of evidence in pipework at ---------- and in the literature indicates that austenitic stainless steel is a suitable material for the transport of hydrogen gas. The work of Vennett and Ansell (Ref 5) also supports this conclusion indicating that embrittlement would only occur if the stainless steel were to be plastically deformed while in the high pressure hydrogen environment. However, since it is much less prone to the formation of deformation induced martensite, it would be prudent to specify 316L for new systems to cater for accidents where pipe containing high pressure hydrogen could be accidentally deformed due to impact (e.g. falling objects, in plant accidents, collisions, etc.)

References

1. Handbook of Stainless Steel. Peckner & Bernstein 1977 ISBN 0-07-049147-X
2. Effects of high pressure hydrogen on metals at ambient temperature. Walter & Chandler. Report R 7780-1 (access No N70-18637) Rocketdyne Div., Rockwell Intl., Canoga Park, Calif Feb 1969
3. Effects of hydrogen on the mechanical properties of low carbon and austenitic steels. M.R.Loutham, Jr Savannah River Laboratory "Hydrogen in metals" P53-75 ASM, Ohio 1974
4. Ductility losses in austenitic stainless steels. A.W.Thompson ibid.
5. The Effect of High Pressure Hydrogen on the Tensile Properties and Fracture Behaviour of 304L Stainless Steel. Vennett & Ansell Trans. ASM Vol60 1967
6. Hydrogen Embrittlement of Metals Louthan et al Materi Sci Eng 10 (1972)

Addendum.

In Nov 2002, two 304 vessels in the demethanizer circuit of an olefins unit developed through wall cracks and leaks. These occurred in the 2:1 elliptical heads which were in the cold worked (as spun) condition. This was attributed to hydrogen causing embrittlement of the deformation induce martensite in the heads. It was recommended that all such heads should be solution annealed after forming.

Reference: IChemE S&LP SG Newsletter Issue 24 Autumn 2003.