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LOW CYCLE FATIGUE TESTING IN HIGH PRESSURE GASEOUS HYDROGEN USING TUBULAR SPECIMENS

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Advantages of tubular specimen

Strain controlled fatigue testing in high pressure autoclaves is difficult to perform and requires expensive specialized equipment and facilities. Pressure must be held constant, sometimes over several days. Precise strain gauges have to operated in hydrogen atmosphere without drifting over the same time, which can be challenging [1]. Heating and cooling is often impossible and otherwise limited in range and speed.

Tubular specimen offer an alternative approach for tensile and fatigue testing. A tubular specimen contains an axial hole where the hydrogen pressure is applied while the outside contour is that of a conventional specimen. This approach has several advantages:

- The measuring equipment has no exposure to hydrogen.
- Existing test capacity can be repurposed for gaseous hydrogen testing quickly and at little cost.
- Low hydrogen volume means little to no safety requirements in the lab.
- External heating and cooling are easily realized (see e.g. [2]).

Test material and specimen preparation

Fatigue testing was conducted on tubular specimen from two pipelines made of X52 and X56 respectively. The holes were drilled into the specimen blanks before the outer contour was manufactured. Some boreholes were honed after drilling. Testing was done in air and with hydrogen introduced into the borehole. Reference tests of conventional specimen were likewise done in air and a conventional autoclave.

Results

Stress and strain

Figure 1 shows hysteresis loops for hollow and conventional specimen with and without hydrogen. A total of five different testing machines at two institutes are included. This shows that cyclic deformation was not noticeably affected by hydrogen or specimen geometry and proves a high degree of reproducibility.

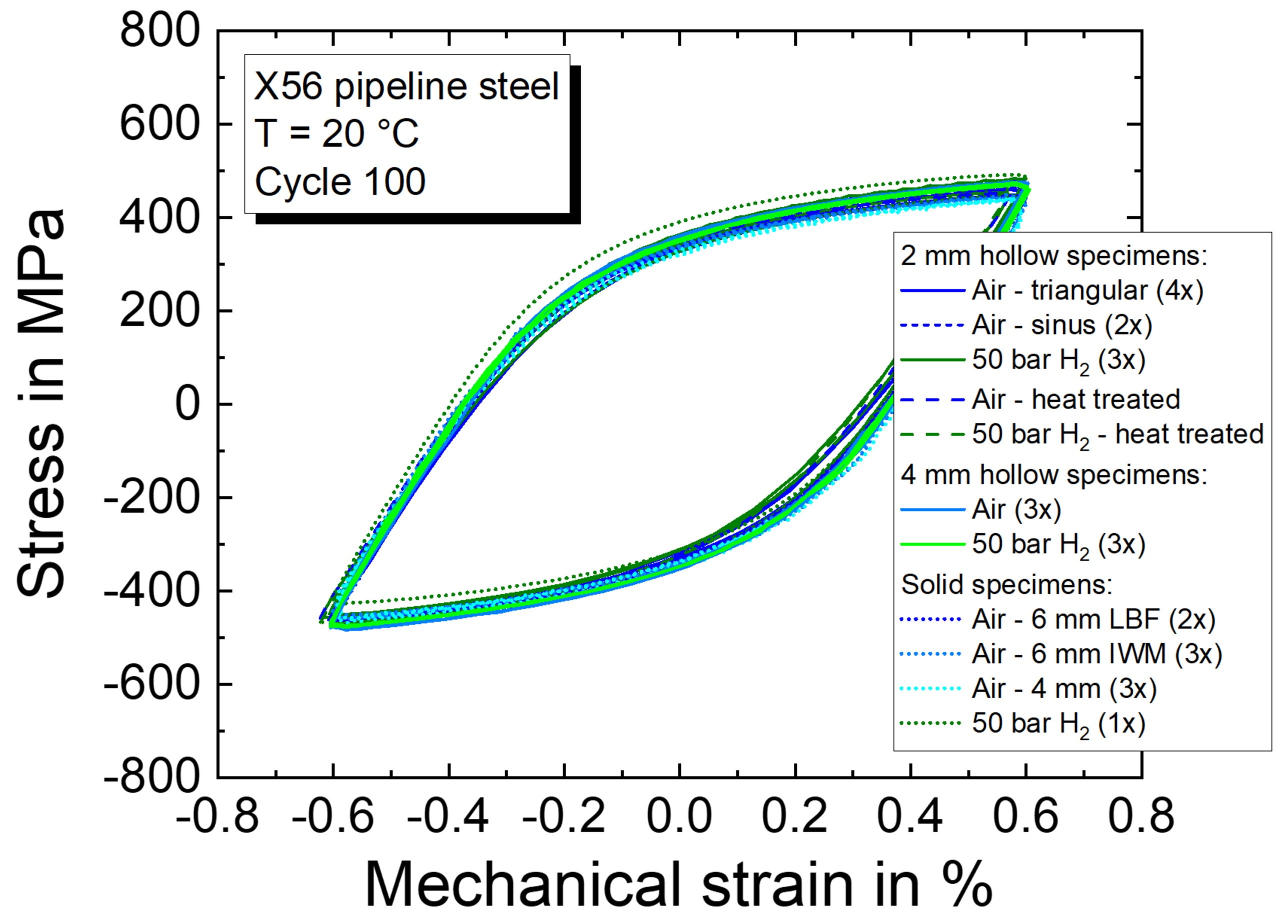

Figure1: Cyclic stress-strain hysteresis of cycle 100 of different fatigue test with amplitude 0.6%.

Fatigue life and fatigue damage

Hydrogen had a pronounced detrimental effect on fatigue lifetime which increased with higher amplitudes. In-air testing showed slightly lower lifetimes for the tubular specimen compared to conventional specimen. The scatter of the in hydrogen tests were significantly increased compared to air testing.

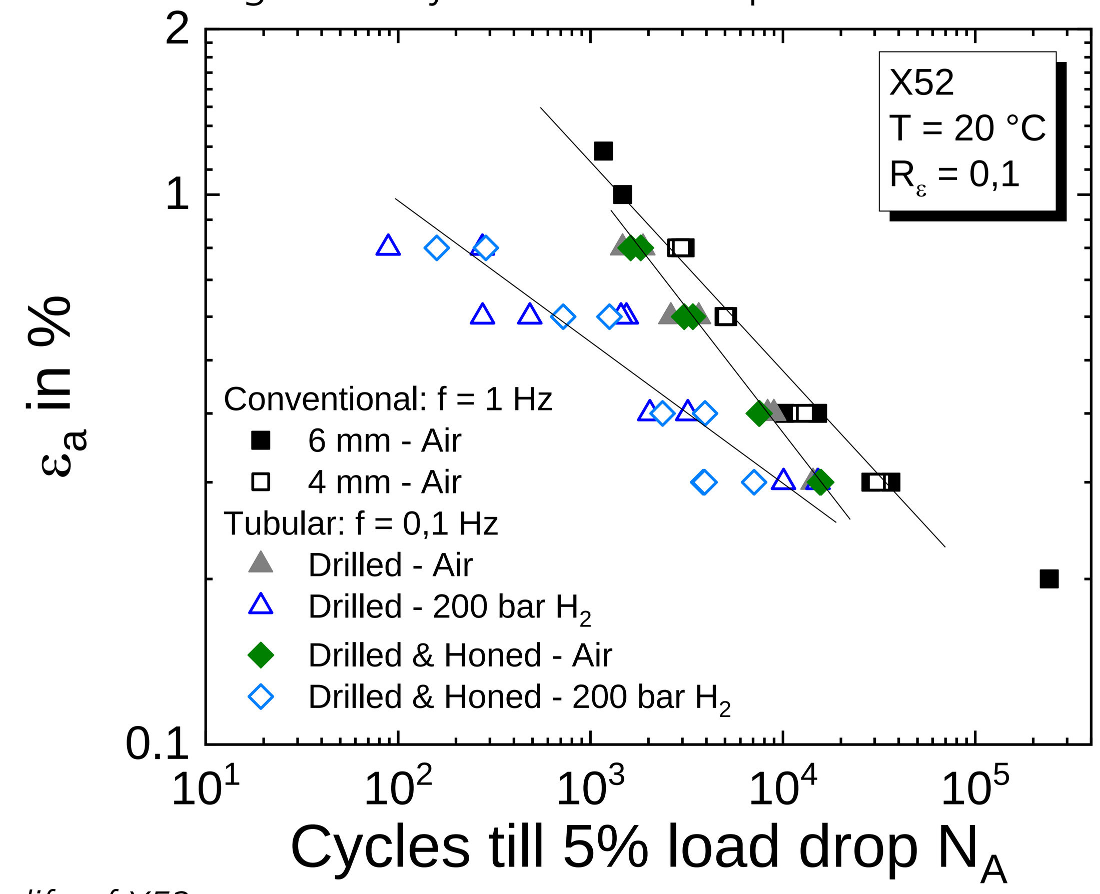

Figure 2: Fatigue life of X52

SEM analysis of the broken specimen showed distinct differences between H2 assisted crack growth till leakage and the following traditional crack growth with visible stations. Crack initiation occurred on the inside wall when hydrogen was present but on both inside and outside wall for in air testing.

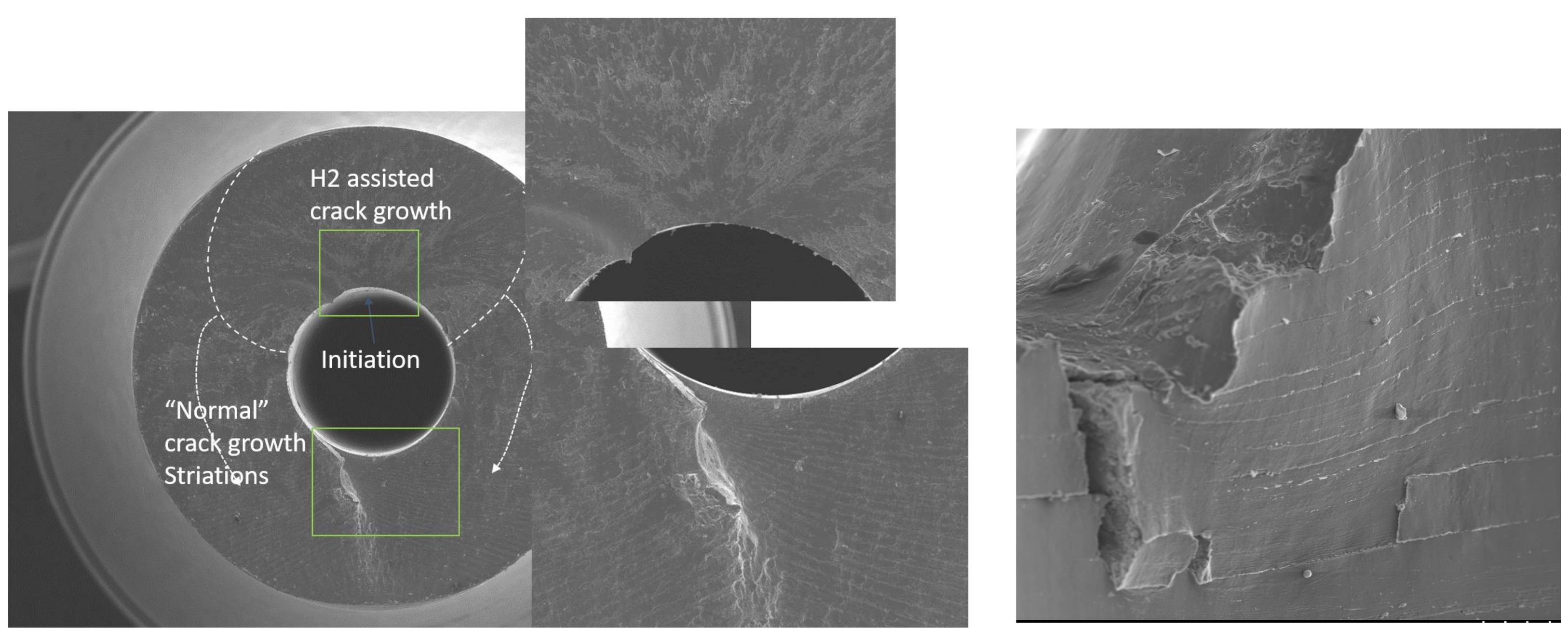

Figure 3: SEM investigation of two cracked tubular specimen tested with 50 bar of hydrogen inside.
Left: Looking onto the crack surface *Right: Looking on the inside wall*

Surface quality and effect

Surface roughness of the as drilled specimen was R_a= 0.13 µm, but visible grooves gave R_z= 2.3 µm. Honing actually increased roughness (R_a= 0.24 µm, R_z= 4.9 µm, but effect on fatigue life was not noticeable in either air or hydrogen (see Figure 2). In some cases the crack seemed to be guided by the grooves (see Figure 3 right). High surface roughness could explain the decreased in air lifetime of tubular specimen in Figure 2.

Further research

The authors are continuing their work by comparing tubular and conventional specimen in other material classes. They are also investigating ways to improve the internal surface quality.

[1] Matsuo et al: „Development of New Strain Gage for High-Pressure Hydrogen Gas Use" Experimental Mechanics (2014) 54:431–442
[2] Ebling et al: „Hydrogen effects on low cycle fatigue of IN718 at RT and 77K using the tubular specimen technique", Proceedings of the Fourth International Conference on Metals & Hydrogen, 2022

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