**Summary**
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# Executive Summary

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# Executive Summary

Within the current activity, ET adapted its cryogenic material laboratory to high pressure / cryogenic testing. With this extension a new approach towards realistic material characterization was realized.

With the smart technical approach under the activity the combination of high pressure conditions and cryogenic temperature / media is possible. Figure 1 shows the set-up suitable to accommodate various test specimens. The cryogenic infrastructure and set-up was already working at ET. By connecting it to the high pressure supply also already existing at ET, the high pressure part was added and integrated into the testing machine.

For the high pressure / cryogenic test method set-up hollow tensile specimens were pressurized from the inside with the mentioned high pressure feedline. Several static and dynamic tests were performed to validate the method. The second approach included a single-sided exposure to the pressure of the specimen. To achieve this, disc-shaped specimens were held in place while a pressure ramp was applied until rupture. The tests were performed both at room temperature and at cryogenic conditions, including a full hydrogen embrittlement study according to EN ISO 11114-4:2005 at room temperature.

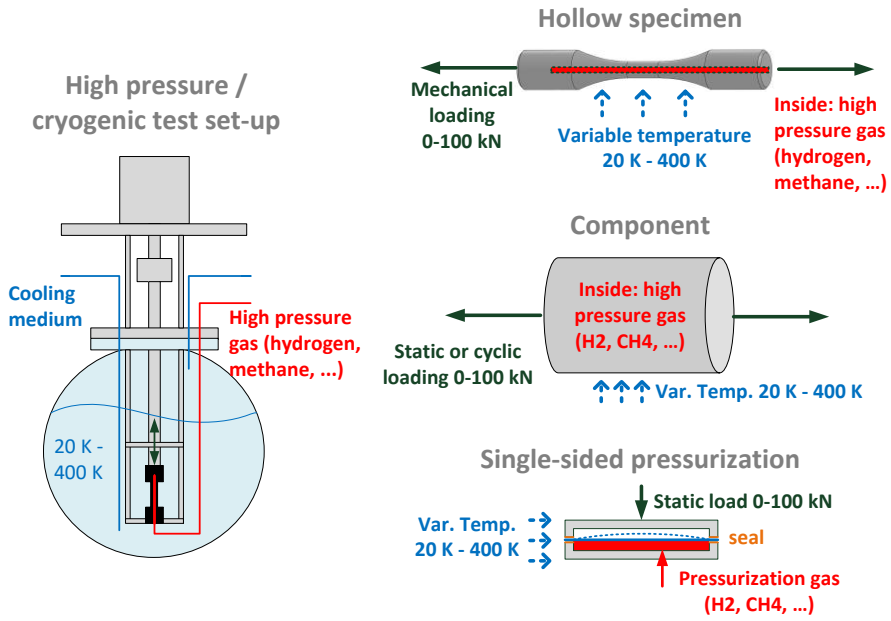



**Figure 1: Scheme of the test set-up**

With the high pressure extension a new approach towards realistic material characterization was realized. Since the pressurized volume is small, the resulting hazards are reduced to a minimum.

Dimensioning, engineering and construction of the modifications as well as the specimens and their holders were part of current activity always keeping in mind the safety requirements for the combined cryogenic and high pressure techniques.

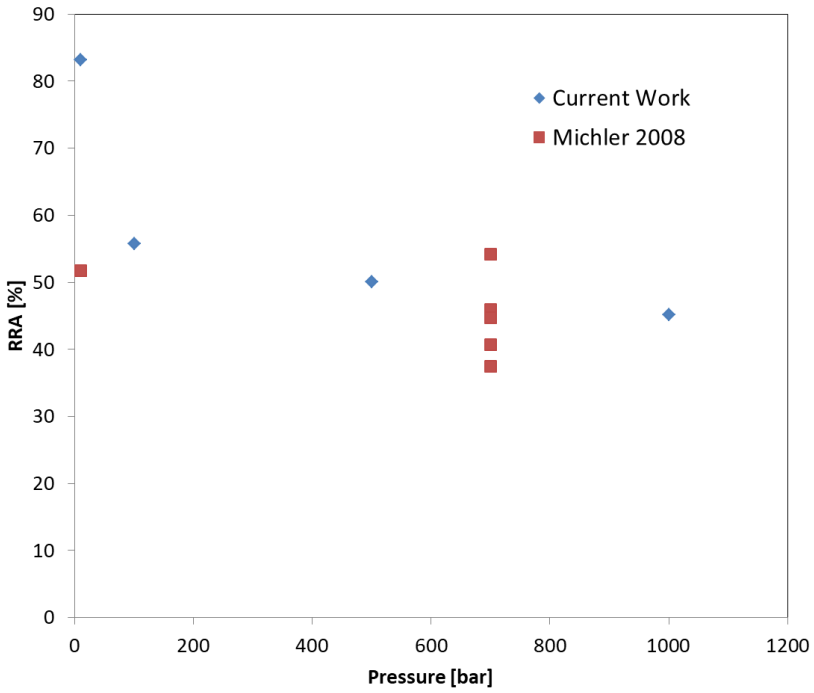
The main tasks to realize the target testing capability were:

- Technical development of the high pressure supply system
- Technical development of the high pressure / cryogenic test method
- Technical development of the single-sided pressurization test method
- Plausibility check (testing) and proof of concept

After the plausibility check, a study of the temperature dependence of the hydrogen embrittlement of EN 1.4301 followed for proof of concept. Tensile, fatigue and disc rupture tests with 1000 bar He or GH2 were performed at room temperature, 77 K (LN2) and 20 K (LH2).

EN 1.4301 is well known to be very susceptible to Hydrogen environment embrittlement and was therefore a key candidate to show the reliability of the new smart technical approach developed at ET. Both the high pressure / cryogenic material testing set-up for in-situ testing in cryogenic fluids as well as the single sided pressurization method were validated for basic functionality using this steel.

Hydrogen environment embrittlement is generally observed with the relative reduced area (RRA). There is no hydrogen embrittlement when the RRA is close to 100%. The following figure shows a comparison of the RRA values measured during this work with a reference from the literature (Hydrogen environment embrittlement testing at low temperatures and high pressures. Michler, T., Yukhimchuk, A. & Naumann, J. Corrosion Science 50(2008), 3519-3526). The results are comparable they show a high sensitivity to embrittlement with a minor dependence to the pressure.




The study of hydrogen environment embrittlement is now possible with different methods. Problematic is the notch sensitivity which is increasing with decreasing temperature leading to a fracture of the specimen in the beginning of the radius in the tests in LH2. For further experiments a greater radius should be realized to avoid this effect. For fatigue tests specimens with a continuous radius between ends (hourglass-shaped specimen) according to ASTM E466 are favored.