

OBJECTIVE

Evaluate the potential of gas flow through corroded wellbore casing using representative laboratory samples for measuring permeability at different effective stresses.

MOTIVATION

Wellbore leakage is a widely known problem especially in geothermal wells, CO₂ sequestration wells, and wellbores associated with fluid storage caverns. The major motivation of this study is to investigate whether corroded casing is permeable to gas and can serve as a significant leakage pathway along the wellbore.

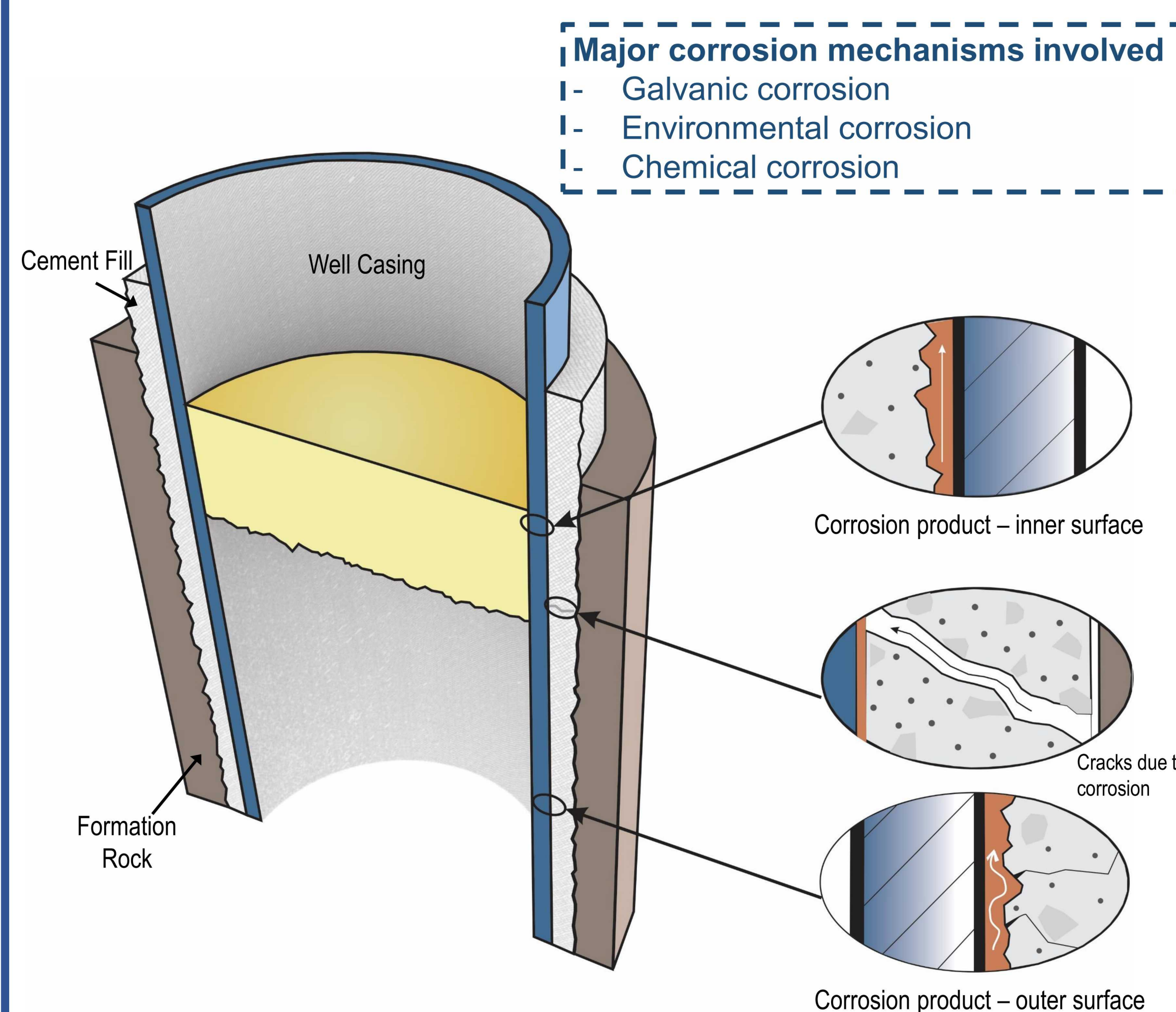


Figure 1: Probable gas leakage path along the corroded casing

SAMPLE FABRICATION

Steel plates, with protection on one side, were corroded in corrosion reactor and placed with molded fusible alloy (wood's metal). Then the assembly of corroded steel and woods metal is sandwiched in a cylindrical assembly (140 mm long, 76 mm diameter), prepared from low permeability cement paste (permeability < 10⁻¹⁸ m²).

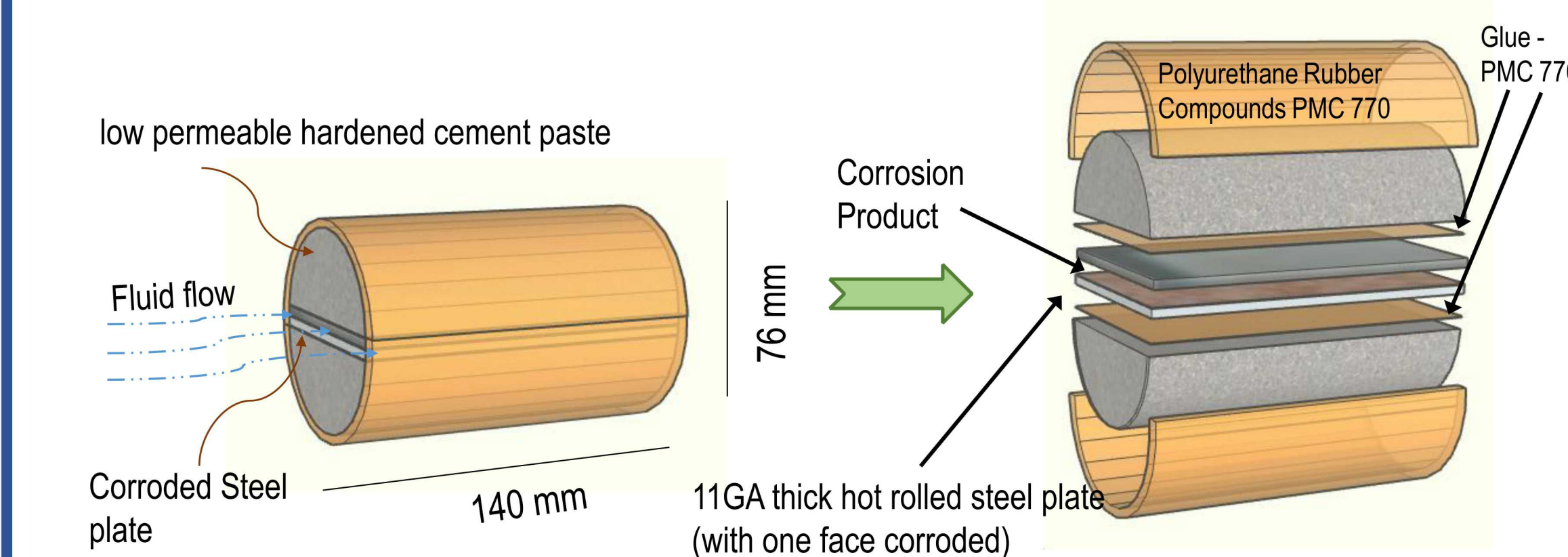


Figure 2: Left, isometric view of sample, right, schematic diagram of sample fabrication for measuring permeability of corrosion product

The primary purpose of the sample fabrication (Figure 2) was to force the pore fluid to flow through the corrosion product only. Gas flow measurements were made on three corroded steel specimen and one intact cement specimen.

RESULTS

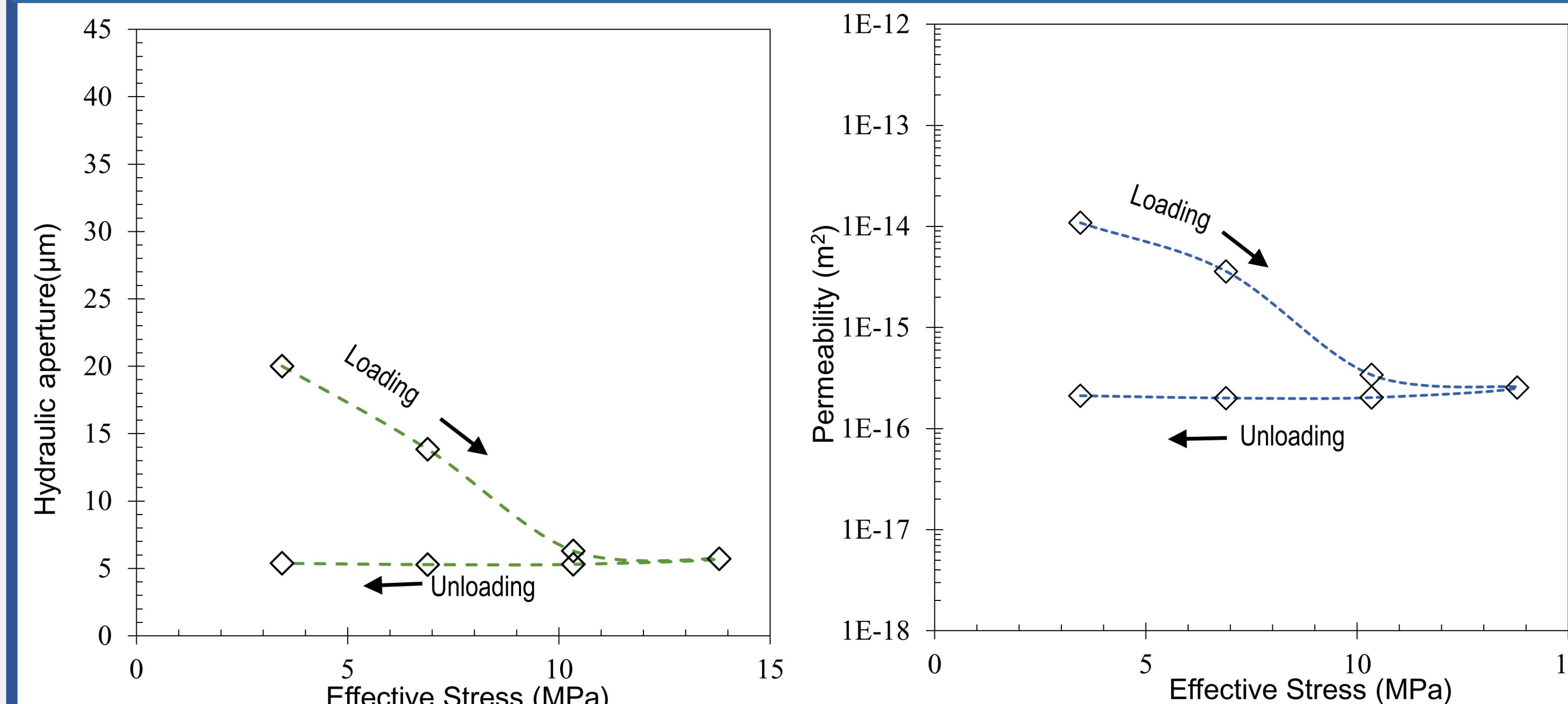


Figure 3: Left, Hydraulic aperture vs effective stress right, permeability vs effective stress for sample CSC 02

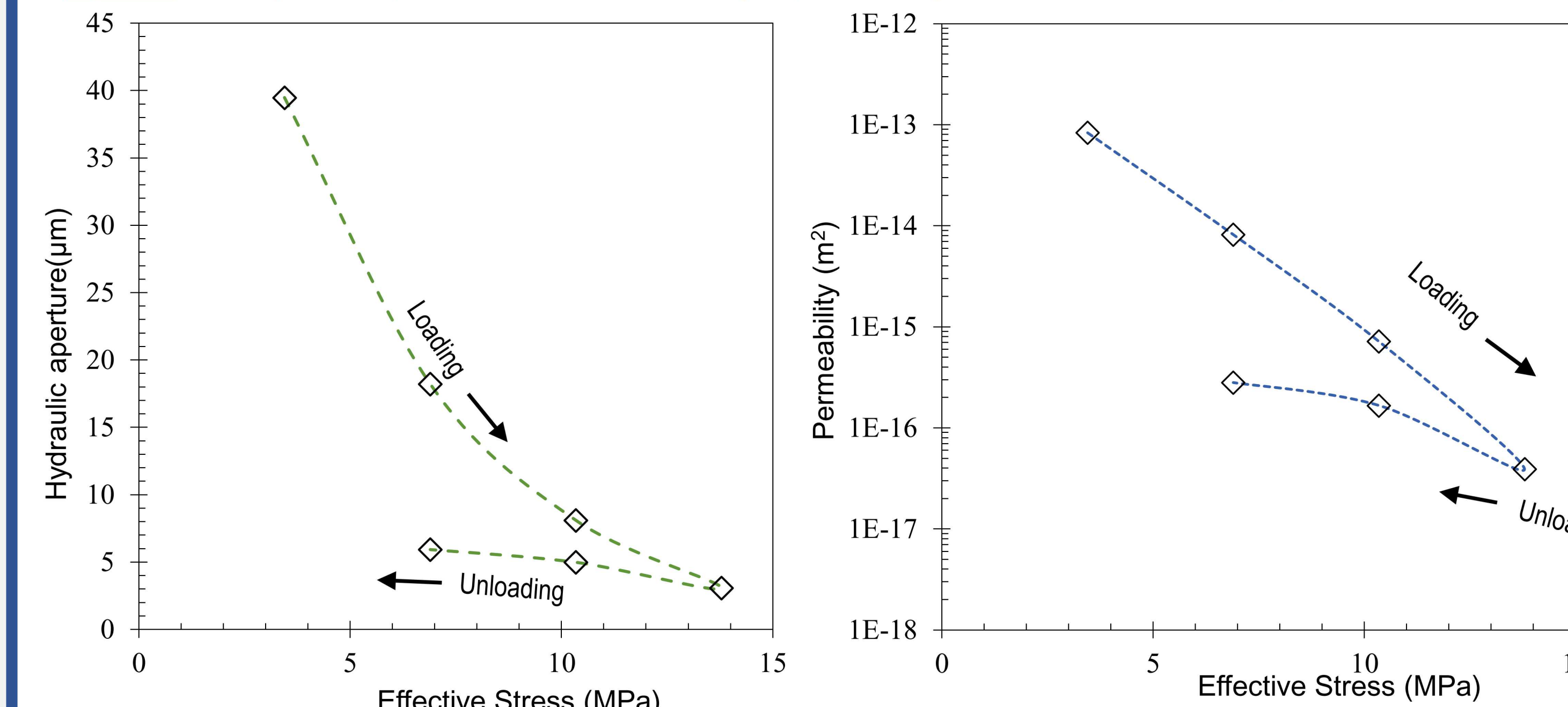


Figure 4: Left, Hydraulic aperture vs effective stress right, permeability vs effective stress for sample CSC 03

Gas flow test under varying stress

Our gas flow testing through the corrosion product indicated that flow included both viscous (Darcy) flow as well as non-linear (inertial) flow. After correcting for inertial flow (by conducting flow tests under a range of pressures), flows were interpreted as effective permeability and hydraulic aperture using the cubic law. We found that the corrosion product was permeable to gas: permeabilities ranged from 10⁻¹³ to 10⁻¹⁶ m².

X-ray photoelectron spectroscopy (XPS)

Sample	Fe ₃ O ₄ %	FeO %	Fe ₂ O ₃ %
CSC 03	16.9	53.5	29.7

Table 1: Composition of iron oxide for sample CSC 03

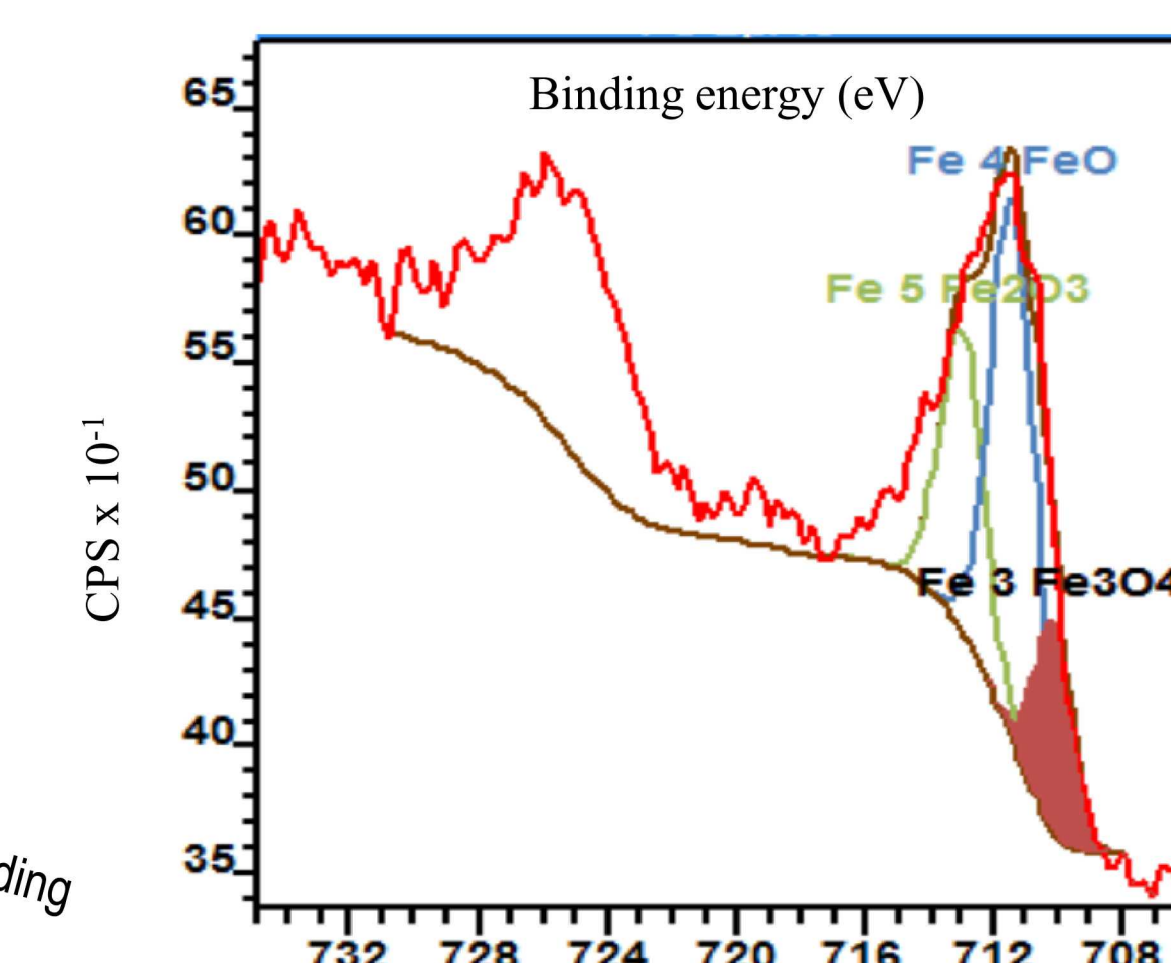


Figure 5: XPS Fe 2p spectra for sample CSC 03

XPS allows the examination of oxidation states of iron in the corroded specimen.

Scanning Electron Microscopy (SEM)

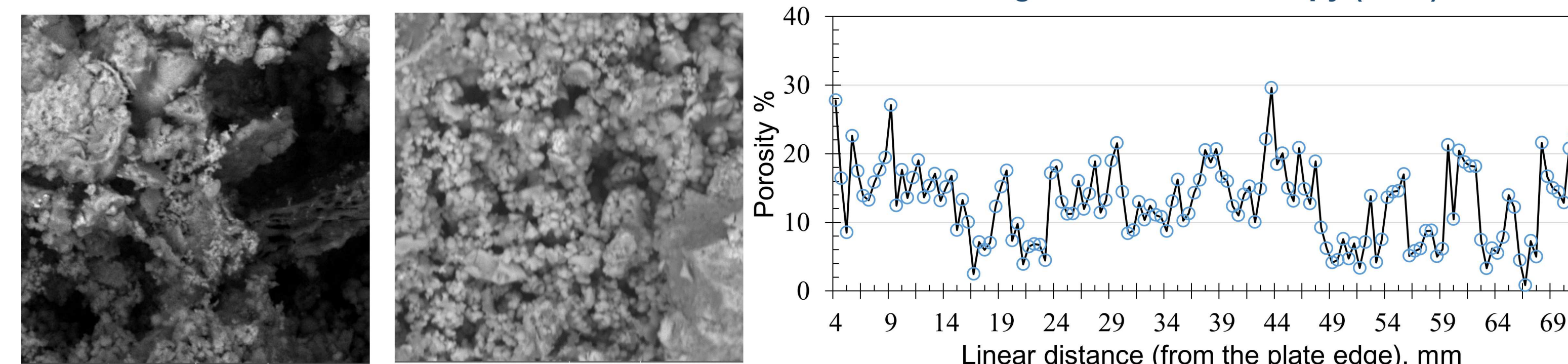


Figure 6: Left, Scanning Electron Microscope (SEM) images (non-coated, low vacuum, backscattered electron imaging) of corrosion product and right, porosity measurement from a series of images for sample CSC 03

Energy Dispersive Spectroscopy (EDS)

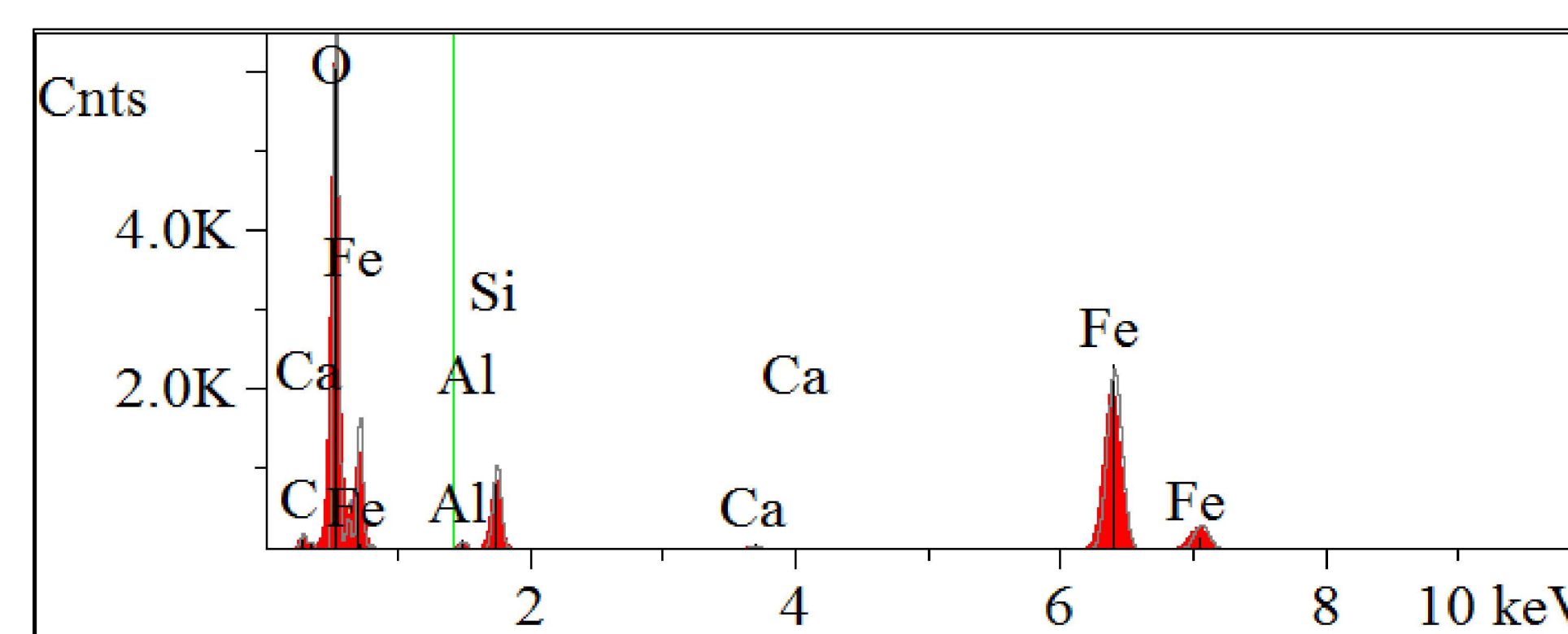


Figure 7: Energy Dispersive Spectroscopy (EDS) spectrum indicating the elemental chemical composition of corrosion product (for sample CSC 03)

Element	Percent present by weight
C	9.21% ± 5.17%
O	47.31% ± 8.93%
Al	0.42% ± 1.16%
Si	6.14% ± 4.30%
S	0.48% ± 1.24%
Ca	3.89% ± 3.46%
Fe	32.90% ± 8.40%

Table 2: Elemental chemical composition of corrosion product (for sample CSC 03)

From the SEM image analysis (of 138 locations), the porosity of the corrosion product in sample CSC 03 was found to be 12.94% ± 1% (at 95% confidence interval), which indicates that corrosion product on casing steel is a porous medium.

From the corrosion product spectrum analysis, the 95% confidence interval for the percent of all elements present by weight in sample CSC 03 shows that the dominance of Fe and O is evident.

The observations and measurements reported here only apply to the types of corrosion mechanism and the range of stress condition used in this research.

EXPERIMENTAL PROTOCOL

Samples are placed in a pressure vessel. The test sequence comprised of single-phase gas flow measurements at different values of effective stress (ranging from 3.4 to 13.8 MPa).

Table 3: Summary of methods used to corrode sample

Sample No	Method of corrosion
CSC 02	The plate was then placed in a humid room (with a continuous supply of mist/humidity at controlled temperature) to represent atmospheric corrosion
CSC 03	One face protected steel plate corroded electrochemically to represent galvanic corrosion of unprotected steel casing
CSC 04	Cylindrical hardened cement paste with a steel plate (one face protected) placed in the middle - corroded electrochemically to represent galvanic corrosion of protected steel casing

Three most relevant and common corrosion mechanisms of different corrosion rates were used to prepare the specimen to obtain various thickness of corrosion products for and within the time frame of our study.

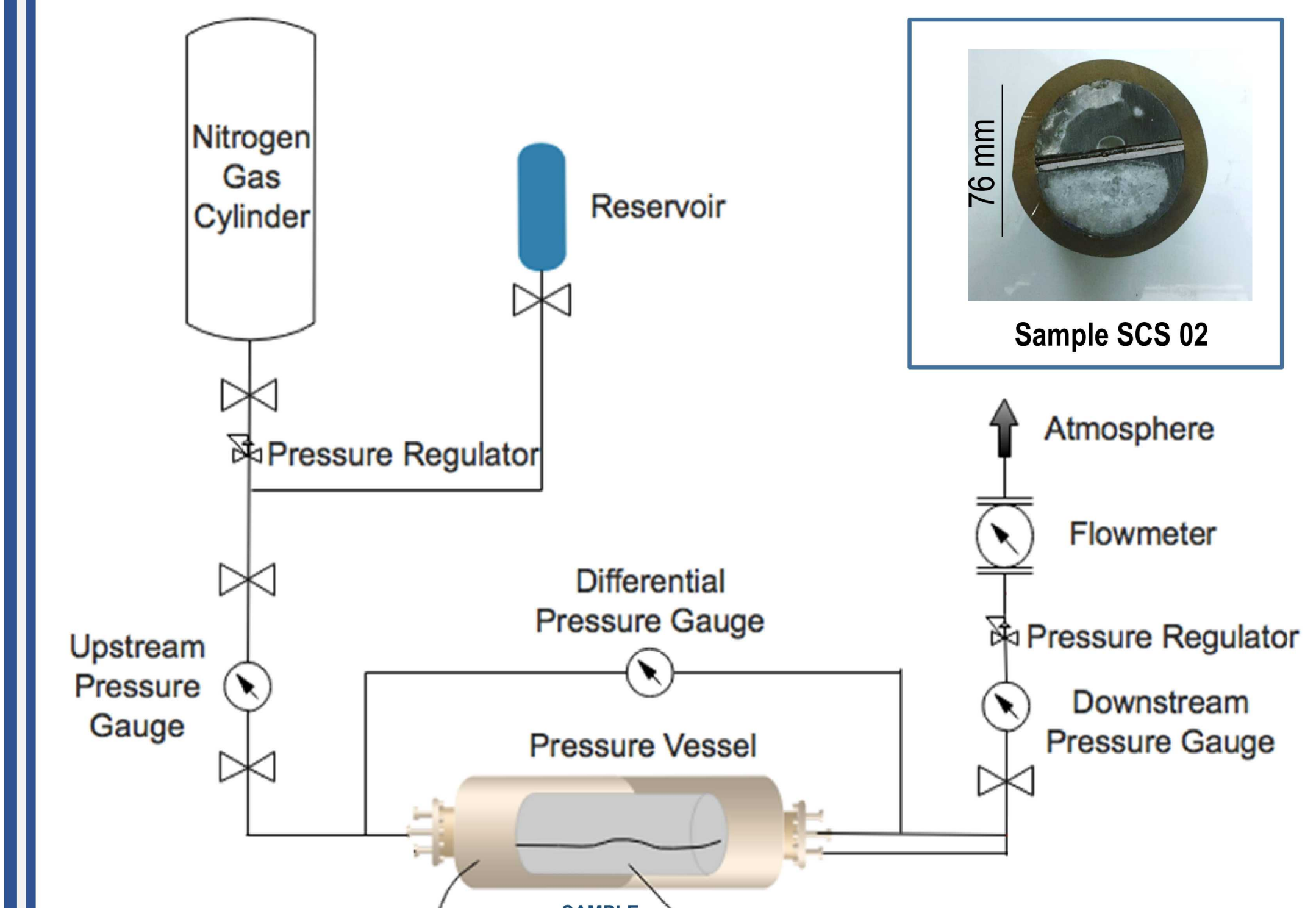


Figure 8: Schematic of flow test configuration

The permeameter system (Figure 8), with a series of measurement devices, valves, tubing and pressure vessel was used to measure the gas pressure and flow through the specimen under confining stress. Nitrogen gas was used as test fluid for all test reported here.

FUTURE PLANS

- Investigate physical and chemical characteristics of corrosion product using microhardness testing, BET, XPS and SEM-EDS.
- Evaluate inertial flow coefficient and show how it varies with effective stresses.
- Evaluate Reynolds number as flow transition criteria (for corrosion product).
- Check the validity of popular semi-empirical formula e.g. Kozeny Carman model, for computing permeability.
- Simulation of gas flow through casing corrosion using experimental data to understand the response of the sustained casing pressure (SCP) at the surface.

ACKNOWLEDGEMENTS

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.