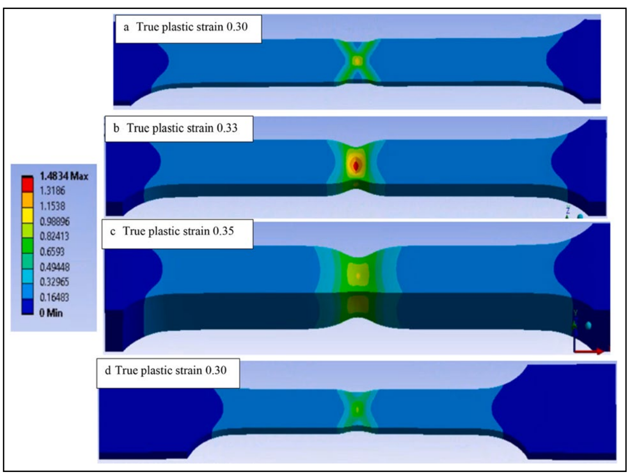
In situ SEM tensile tests reveal bulk scale material behavior

In situ scanning electron microscope (SEM) tensile experiments can be used to understand the onset and evolution of cracks under tensile stresses on samples much smaller than those required by ASTM standards. But how confident can we be with the results generated from such small samples?

In a recent study published in *Materials Characterization* (https://doi.org/10.1016/j.matchar.2021.111614), a research team led by Afsaneh Rabiei, a professor in the Mechanical and Aerospace Engineering Department at North Carolina State University, sought to answer this nagging question. "On the laboratory scale testing, we never really mimic the dimensions of the real-world samples, but the measured yield strength, tensile strength, and elastic modulus on small-scale samples should still be accurate and reliable enough to be used in the real-world application," says Rabiei, "and the question is how can we ensure that the results of these *in situ* SEM experiments are comparable?" Rabiei's group found that *in situ* SEM tensile tests conducted on thinner samples are representative of the bulk scale.

The researchers conducted physical experiments as well as finite element modeling (FEM) simulations. They prepared dog bone samples of Alloy 709, an austenitic stainless steel with high-temperature strength, creep, and corrosion resistance. Both *in situ* SEM tests (on submillimeter thick samples) and *ex situ* tests (on samples up to 5.9 mm thickness) were conducted and the results were compared with FEM simulations. "There are currently no ASTM standards available for *in situ* SEM tensile tests, so we designed our samples considering *ex situ* tensile test standards, number of grains in the cross section, as well as the constraints with the SEM loading stage," Rabiei says. All the tests were conducted at room temperature and the results were correlated with the number of grains within the specimen's cross section. The same strain rate of 5.02×10^{-3}/min was used across all tests performed.



Finite element modeling results showing thickness effects on the equivalent plastic strain distribution in (a) 0.68-mm, (b) 1.9-mm, and (c) 5.9-mm thick *ex situ* sample and (d) 1-mm thick *in situ* scanning electron microscope sample at similar plastic strain. Credit: *Materials Characterization*.

The samples had 13–118 grains in their cross sections. The results from the tensile tests showed that the 0.2% proof stress and tensile strength were the same in both *in situ* and *ex situ* tests (which had different sample thicknesses). However, the necking mechanism (occurring after the ultimate tensile strength or UTS point) was different between these, with the thicker samples having a more diffuse necking and the thinner samples more localized necking. "These results also confirm the validity of the *in situ* SEM tensile tests conducted on thinner samples as long as the required minimum number of grains exist within the cross section," Rabiei says.

"The higher the number of grains within the cross section of the sample, the more homogenized the distribution, such that test results will be an average rather than a result of individual grains, and this research demonstrates that," says Yongming Liu, a professor in the Aerospace and Mechanical Engineering Department at Arizona State University, who was not involved in this study.

Henry Quansah Afful