



Automated Mechanical Testing System Update

July 2022

Changing the World's Energy Future

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Frank Liou



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Automated Mechanical Testing System

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1- Idaho National Laboratory

2- Product Innovation and Engineering, LLC

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Outline

- Motivation
- Challenges and Opportunities
- AMTS

Motivation

- Need for structural materials for advanced reactor systems^{1, 2, 3}:
 - Higher Energy Neutron Spectrum
 - Higher Temperatures
 - Corrosive Environments
- Research on new materials is being conducted, including on Multi-Principle-Element-Alloys (MPEA's, aka High-Entropy-Alloys, aka Complex-Concentrated-Alloys)
 - In a 2021 review paper⁴, ~4000 papers published on MPEA
 - Of those, only ~100 were focused on nuclear applications and were topical on fabrication, modeling, ion irradiation, and corrosion.
 - Very limited neutron irradiation data on MPEAs
 - Nearly limitless composition space for MPEAs

1 – <https://doi.org/10.1016/j.matre.2021.01.002>

2 – <https://doi.org/10.1016/j.cossms.2016.10.004>

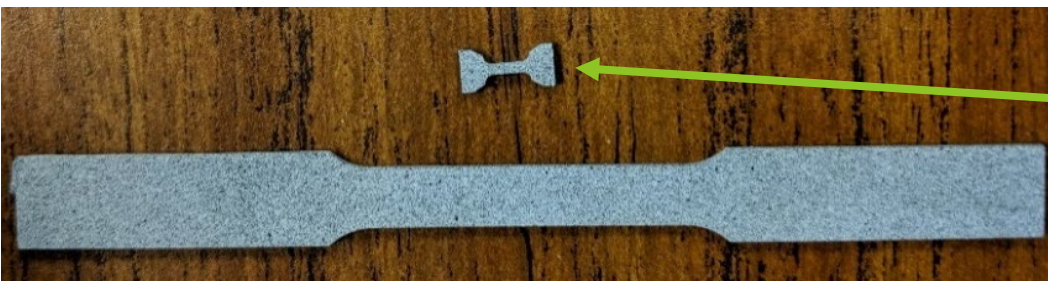
3 – <https://doi.org/10.1038/ncomms13564>

4 – <https://doi.org/10.3390/e23010098>

Challenges and Opportunities

- How to increase throughput, reduce cost, and increase data extracted from each specimen?
 - As of 8 July 2022, 1,683 entries in the NSUF Material Library containing the word “Tensile” in the sample description
 - Future experiments expected to generate large quantities of specimens of reduced sizes¹
 - Automate mechanical testing,
 - Incorporate advanced Digital Image Correlation Analysis
 - Localized Strain Mapping
 - Spatial variation
 - Inhomogeneous materials
 - Etc.

1 – Karnati, Isanaka, Zhang, Liou, Schulthess, “A Comparative Study on Representativeness and Stochastic Efficacy of Miniature Tensile Specimen Testing”, Accepted.

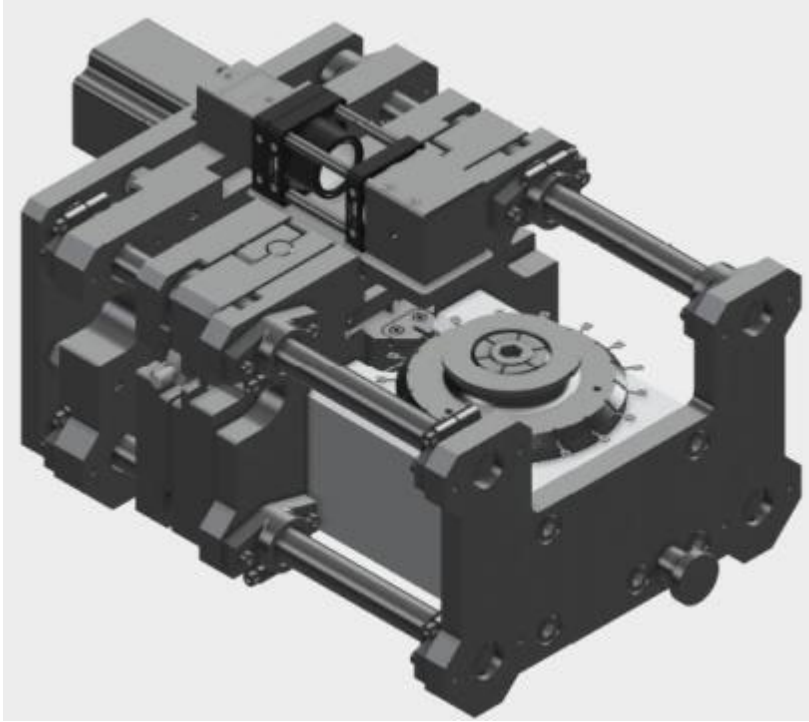


Miniature “MT2” Tensile Specimen
ASTM E8 Standard “Sub-sized Specimen”

AMTS – Automated Mechanical Testing System

- Design driven by the following objectives:
 - Cartridge to hold multiple specimens
 - Automate test process
 - Accommodate small scale specimens
 - Incorporate advanced DIC
 - Automate data analysis
 - Small footprint to limit required space in hotcell

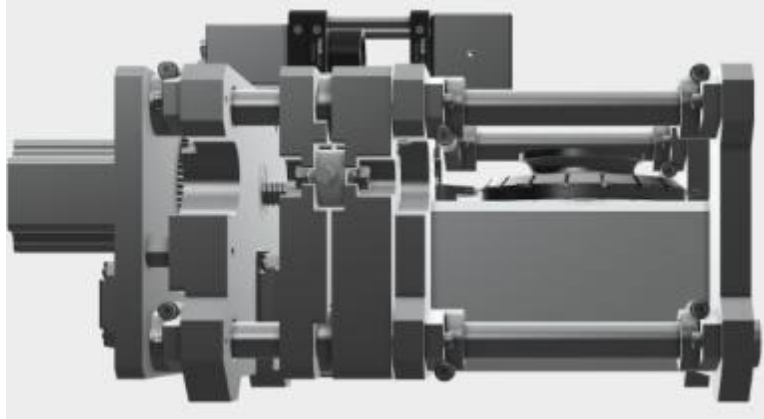
AMTS - Current design



Cartridge assembly has only 3 components

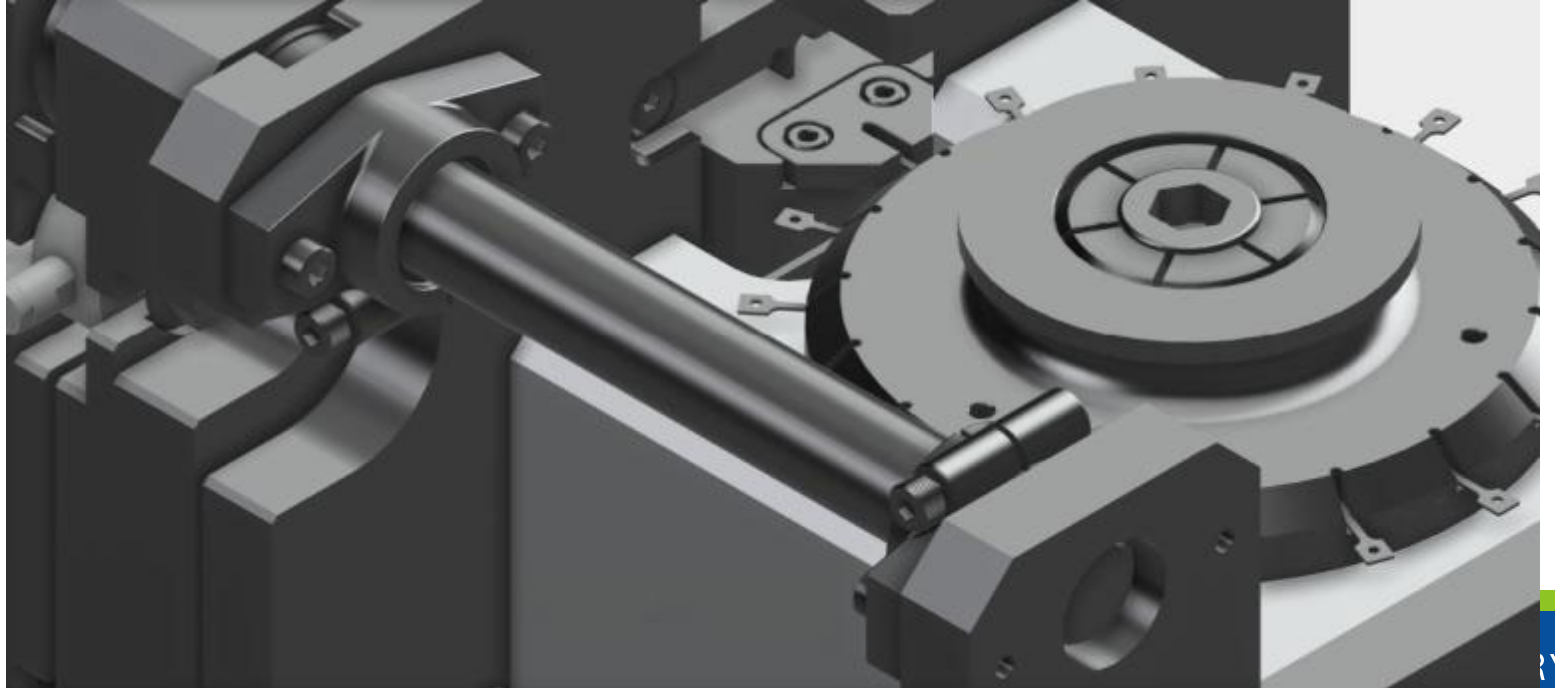
Size and weight accommodate hotcell installation

Cavity space and designed to collect and retain broken specimen

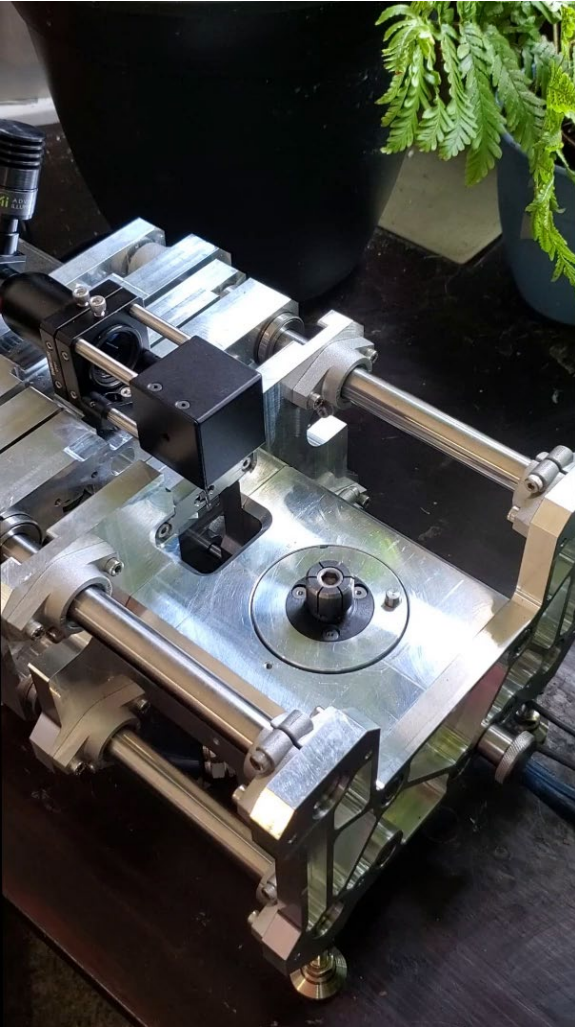


Electronics like motors, loads cells, camera assembly do not have direct line of sight with irradiated specimen

Number of specimen on cartridge is 24



AMTS - Current design

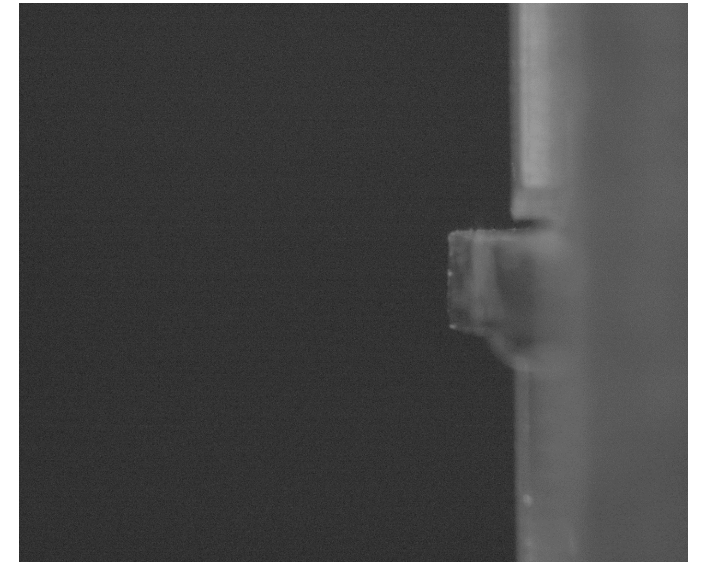


This system weighs just over 30 lbs.

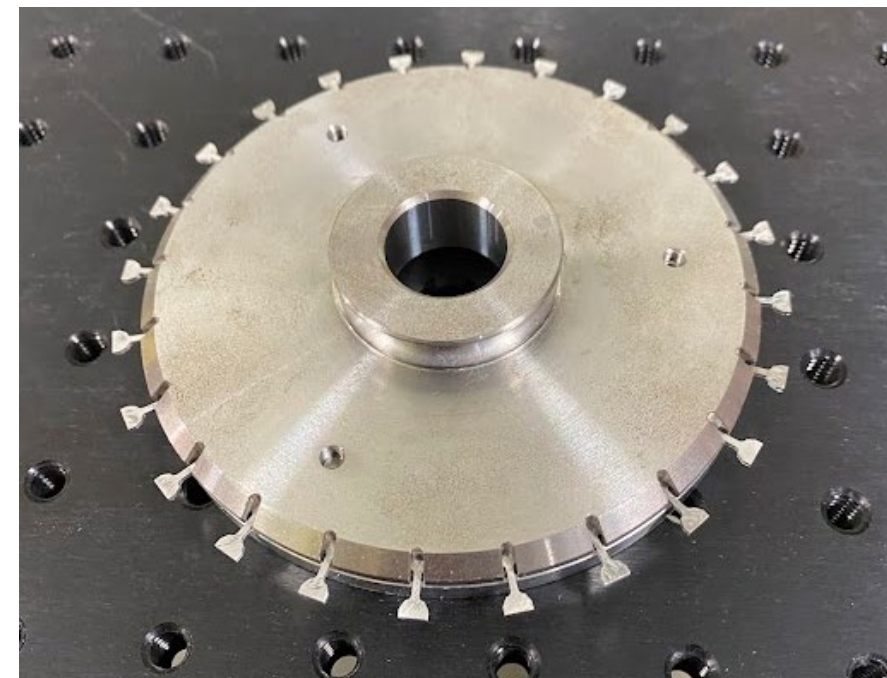
Footprint size is less than 2'*1'.

Cartridge has only 3 major components.
Loading/unloading specimen designed for
hotcell remote manipulators.

Swap cartridges for rapid testing or
different specimen geometry.

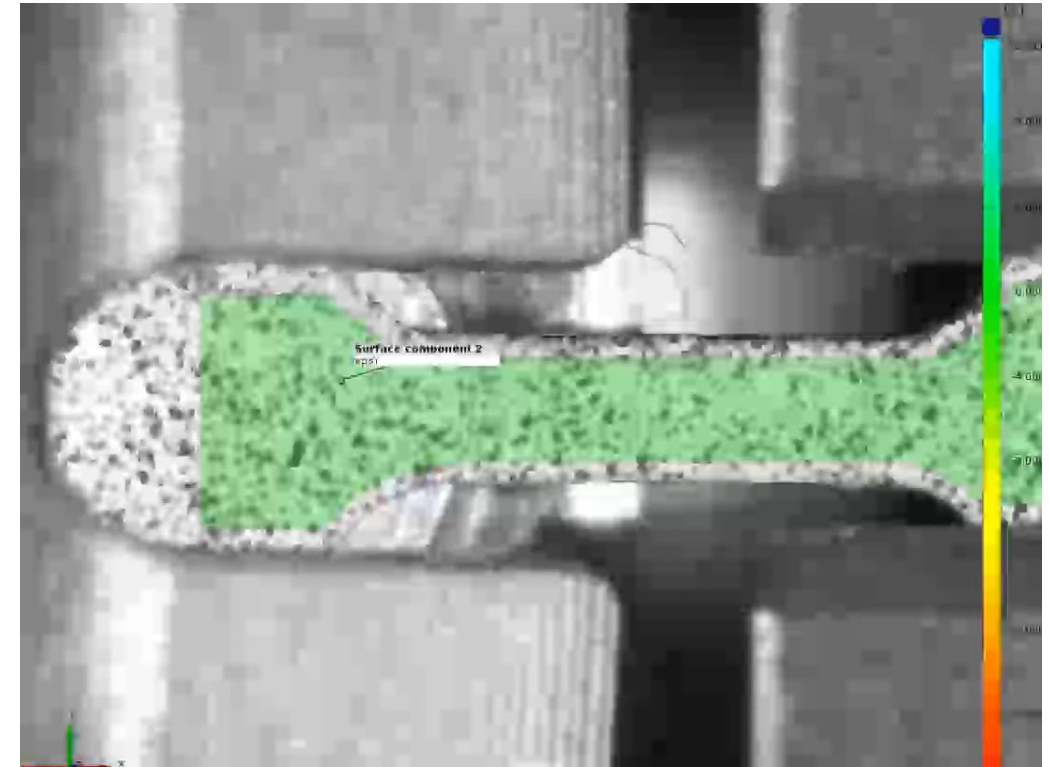
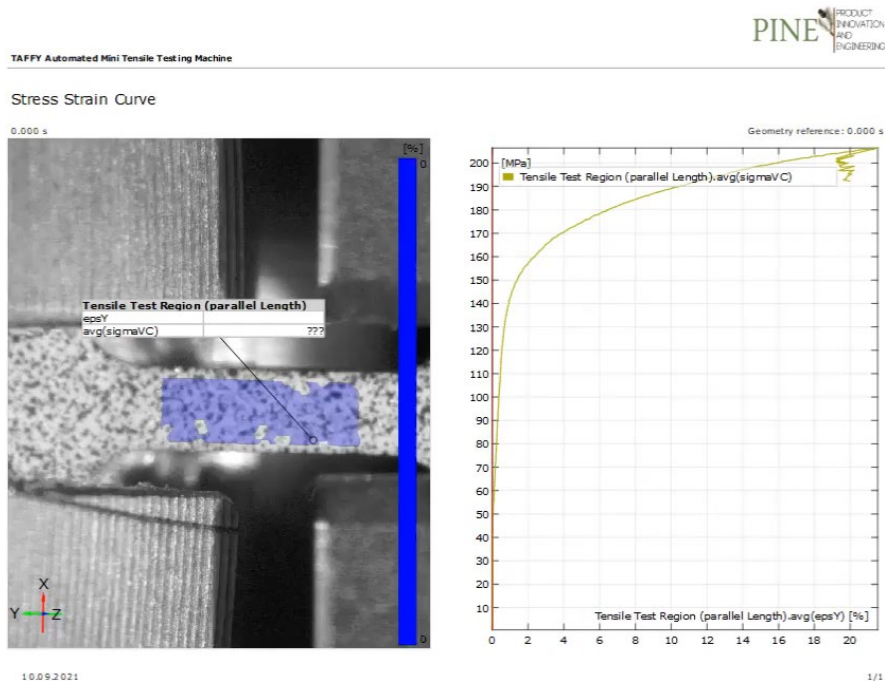


AMTS - System status



System at INL, working through functional testing and preparing for installation in hotcell.

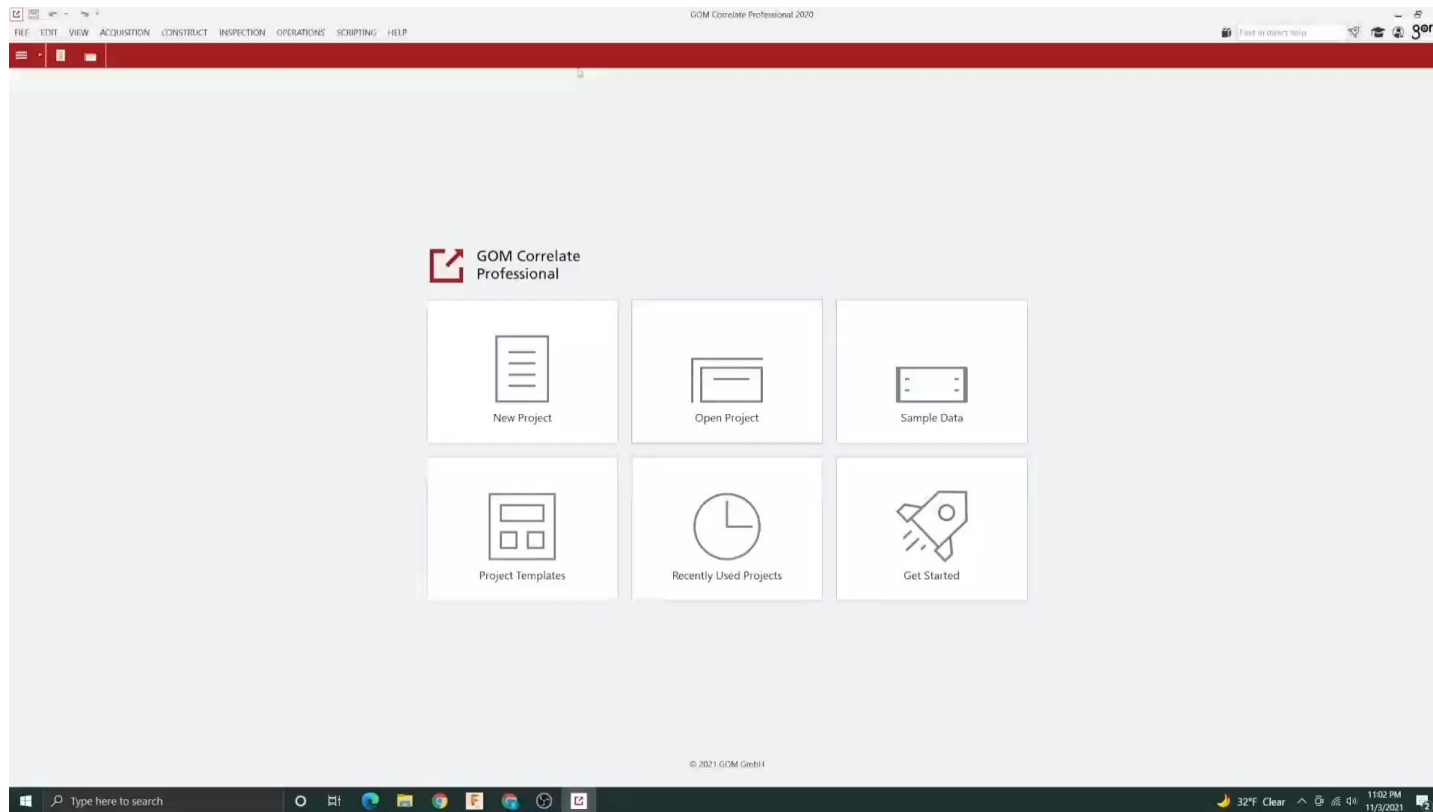
AMTS - Software and data analyses



To facilitate automation and ease in data analysis, we chose an off-the-shelf software that offers scripting features; GOM Correlate

Written our own script to automate data assimilation from load cell and DIC to output the important material and test metrics as shown

AMTS - Automation through software



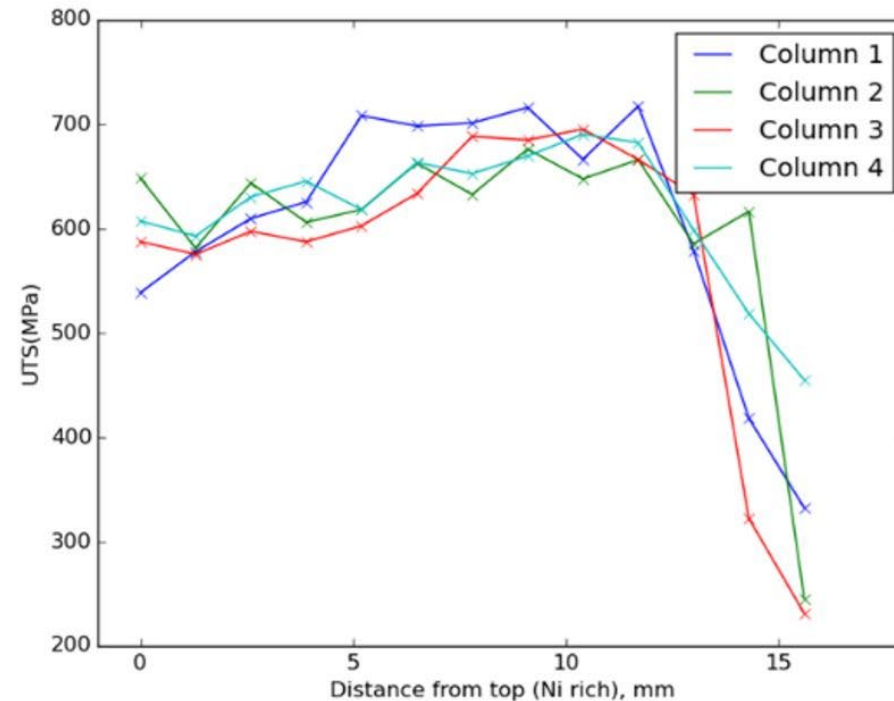
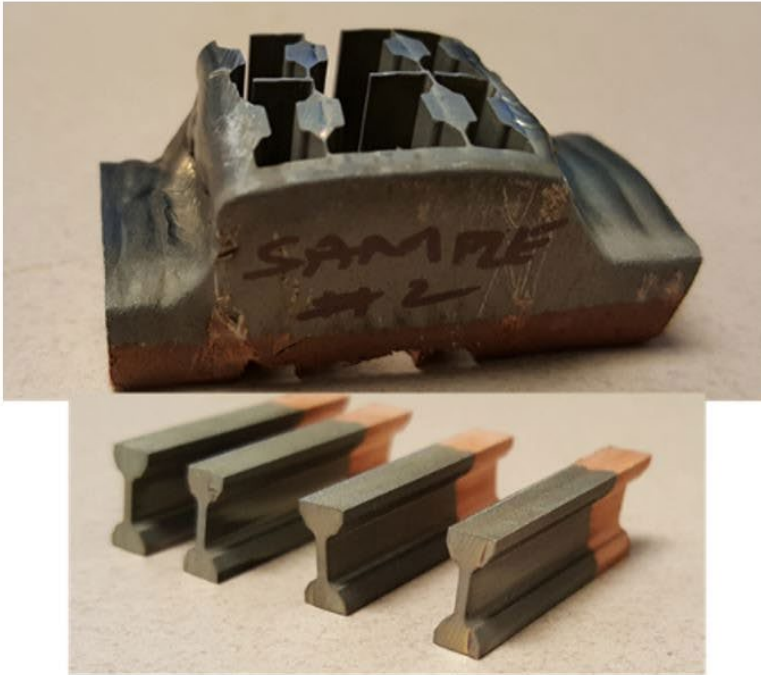
Utilizing scripting features offered by GOM Correlate to improve data sampling and analyses automation

Current operation shown in video

Script provides an intuitive and interactive way to analyze and output the important data

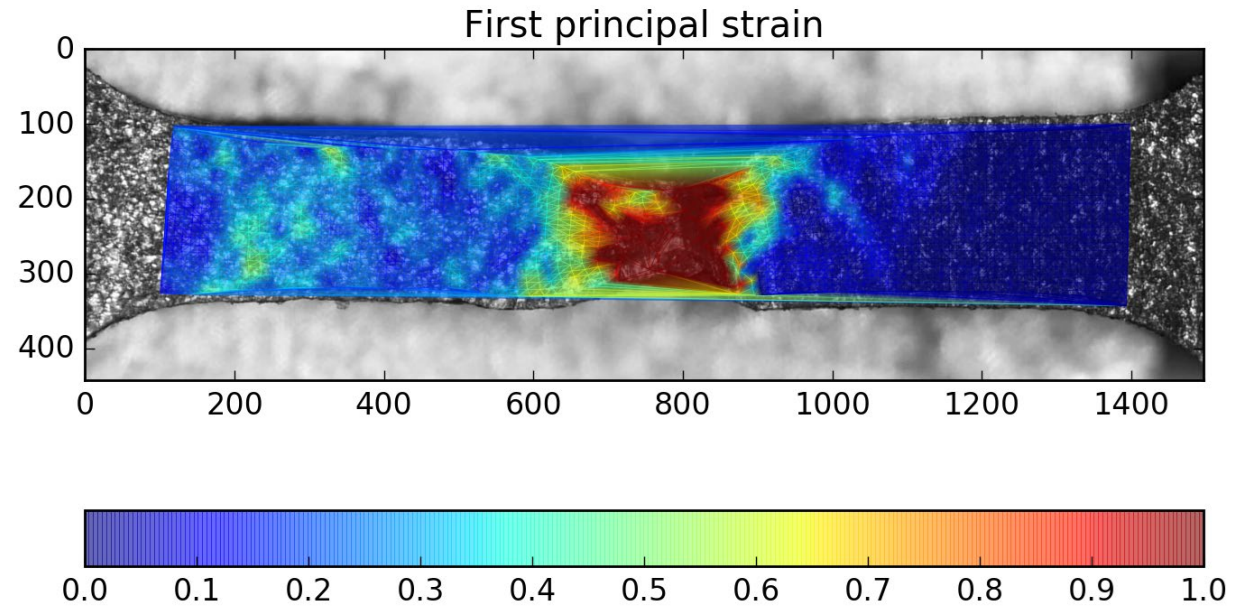
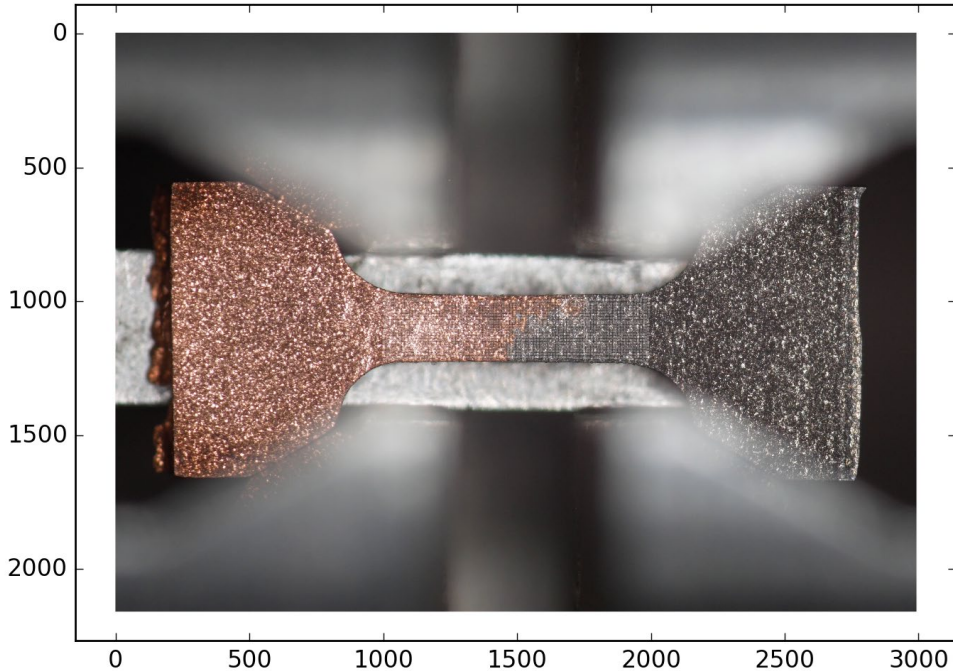
Working on minimizing the amount of user interaction needed such that data sampling and analyses is also streamlined and automated

Potential use: Spatial property characterization

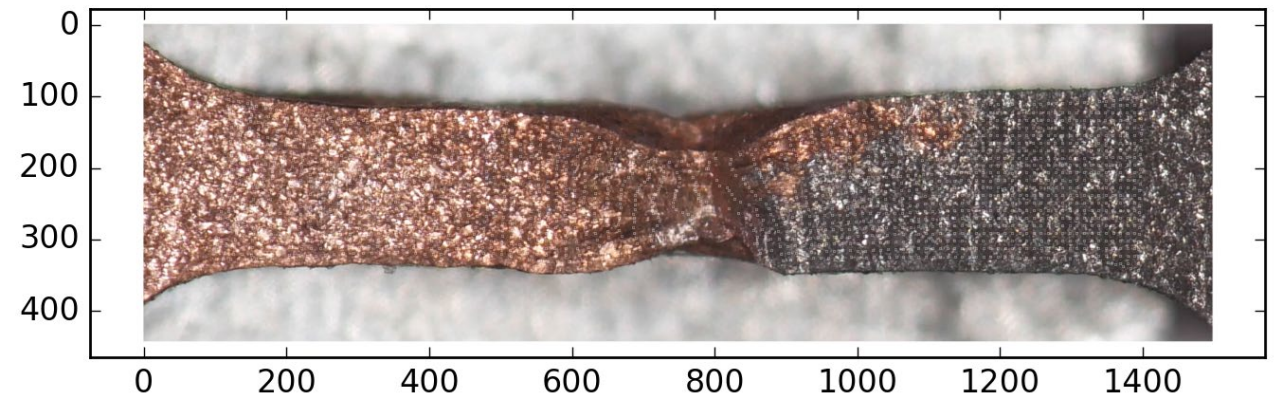


- FGM – Functionally Graded Material
- Each specimen different chemistry
- Variation along gradient, such as damage gradient across reactor pressure vessel wall

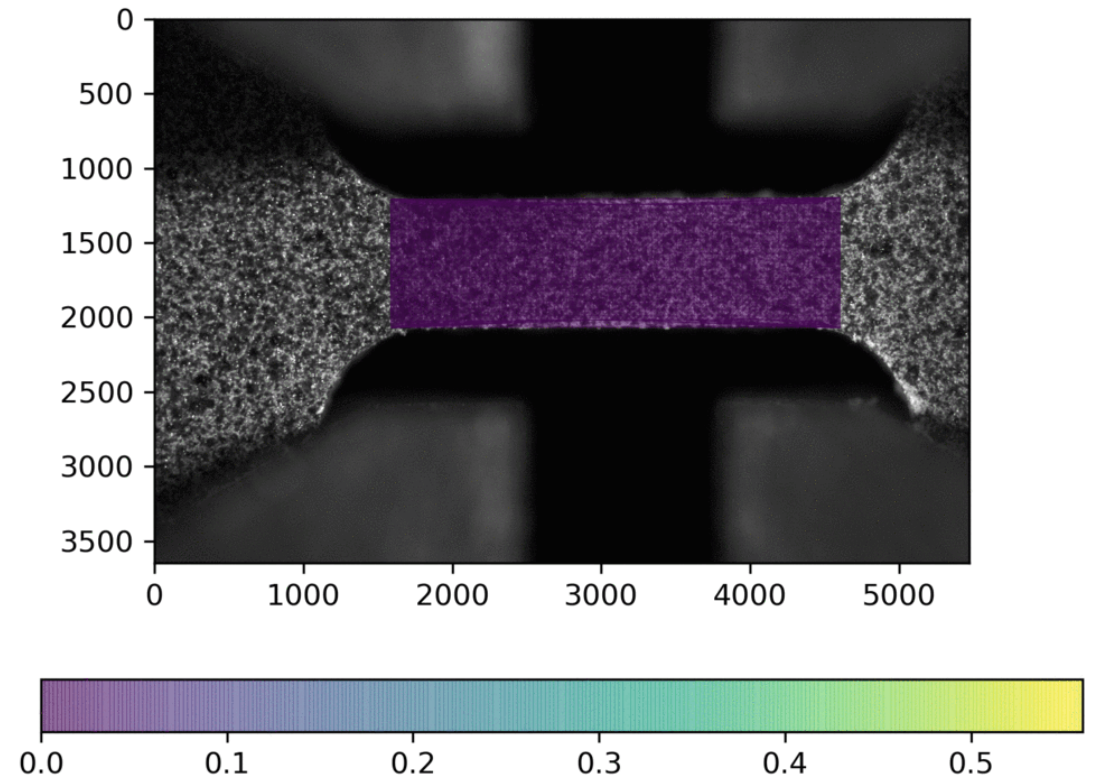
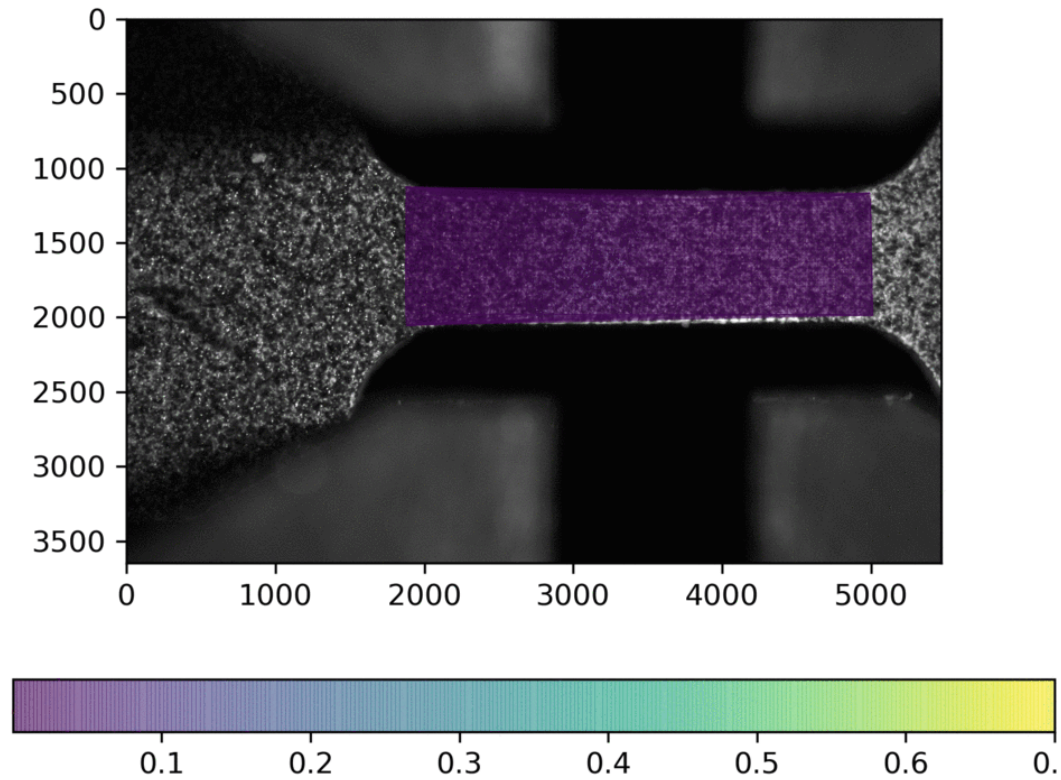
Inhomogeneous material testing



- Cu to Inconel 625 FGM
- Inhomogeneity in materials will lead to failure in the softer material (copper) during tensile testing which was visually captured using the AMT's Digital Image Correlation (DIC) system



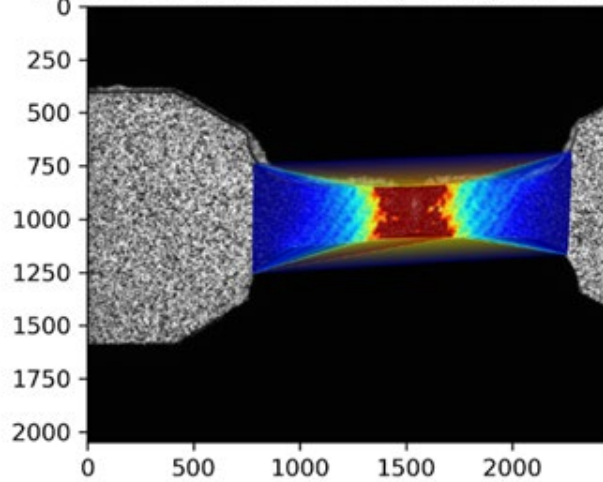
Potential use: Strain Evolution



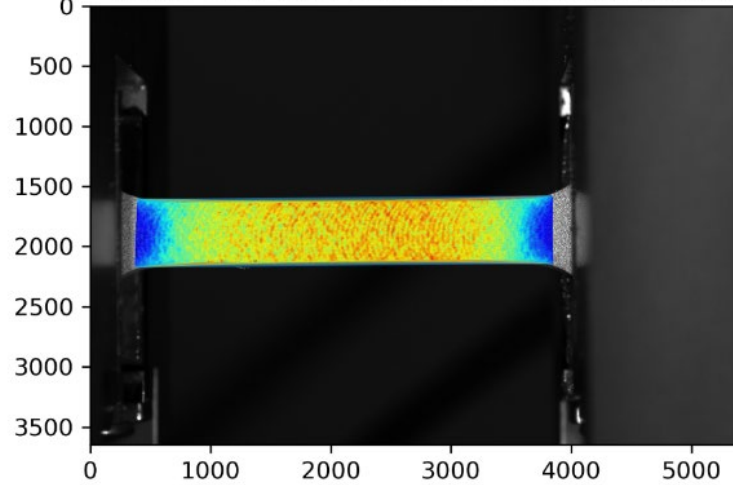
> Inhomogeneous strain distribution

Different Materials and Phenomena

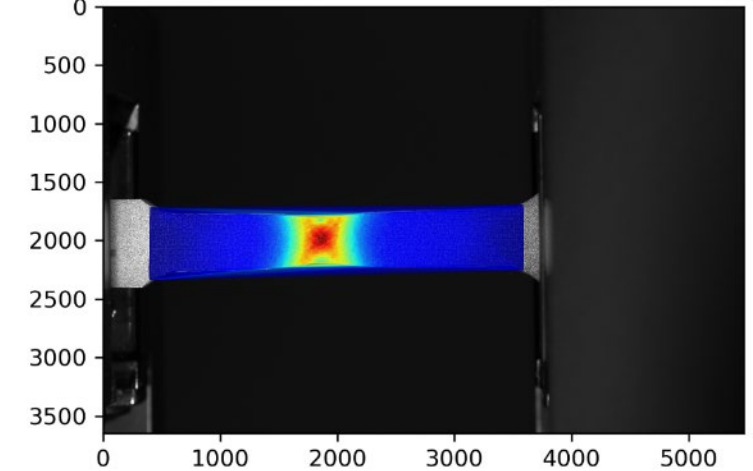
frame 1568, time 196.01s, elongation 21.6%



frame 960, time 120.00s, elongation 13.1%



frame 856, time 171.20s, elongation 15.4%



0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40

SS304L

0.05 0.10 0.15 0.20 0.25

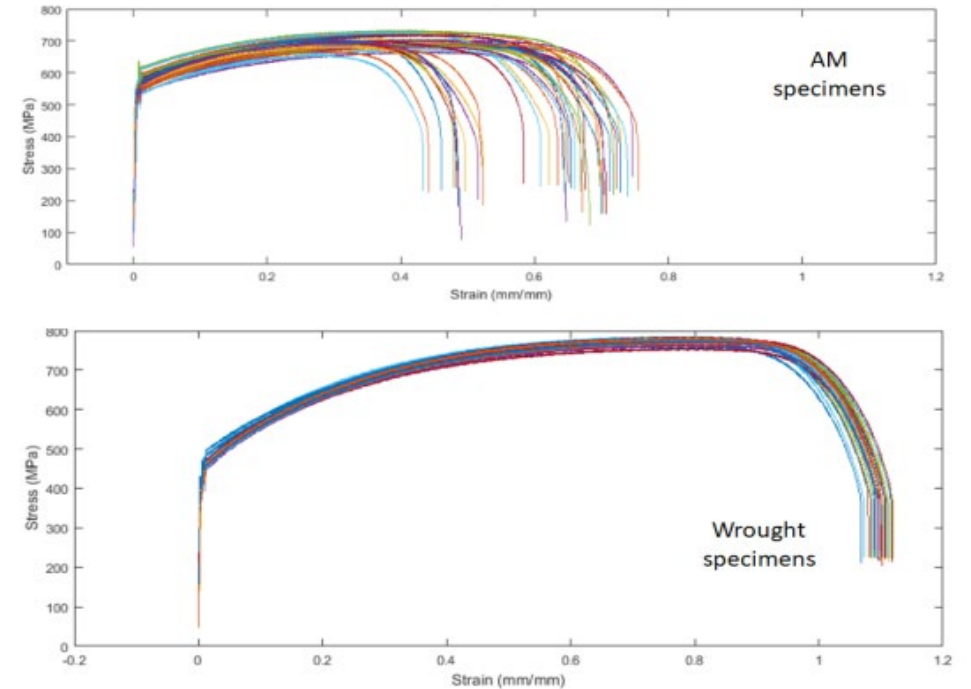
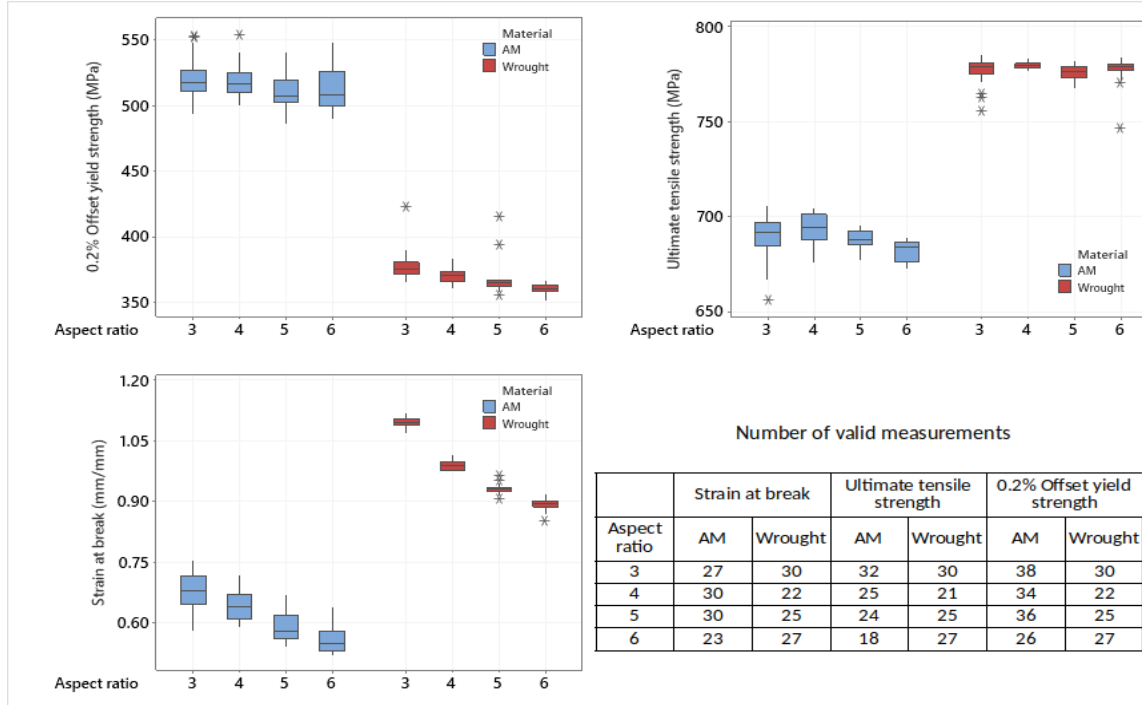
Ti – Strain field

0.1 0.2 0.3 0.4 0.5 0.6

Al 6061-Before Failure

- Effects of strain hardening from CNC machining in Ti strain field image,
- Strain field development in different materials
- Effects observable irrespective of specimen size or material type

Impact and benefits



The ability to rapidly acquire 100's-1000's of data points could have significant scientific and societal ramifications

Scientific: Modern materials and manufacturing processes exhibit critical flaw sizes, inhomogeneity, anisotropy, and other effects that are best identified by miniature specimen and high throughput testing

Societal: Gathering large amounts of data to provide statistical relevance and confidence especially when working with expensive or hazardous materials



Idaho National Laboratory

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