Creep Deformation and the Evolution of Residual Stresses in SOFC Anodes

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Acknowledgments

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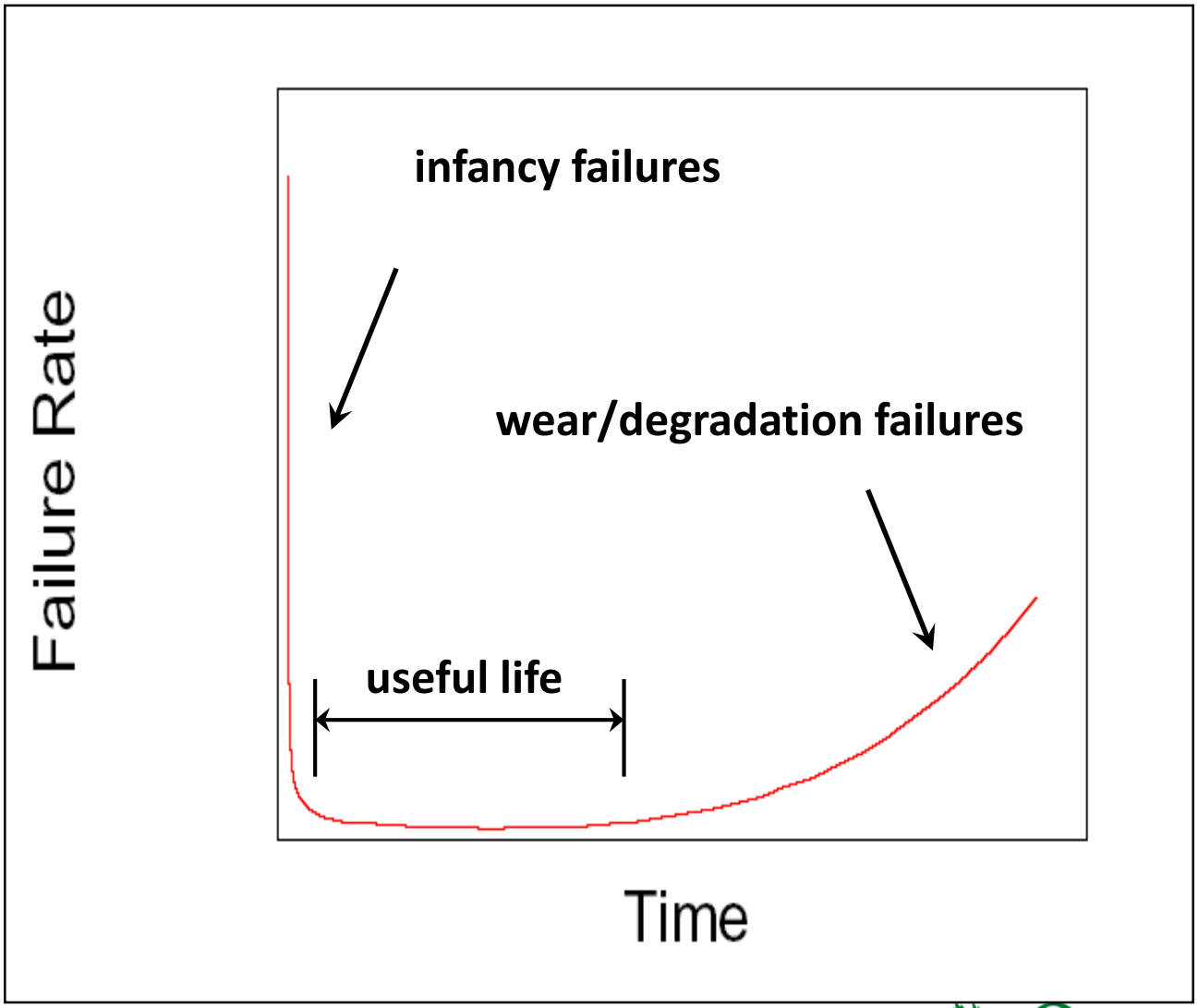
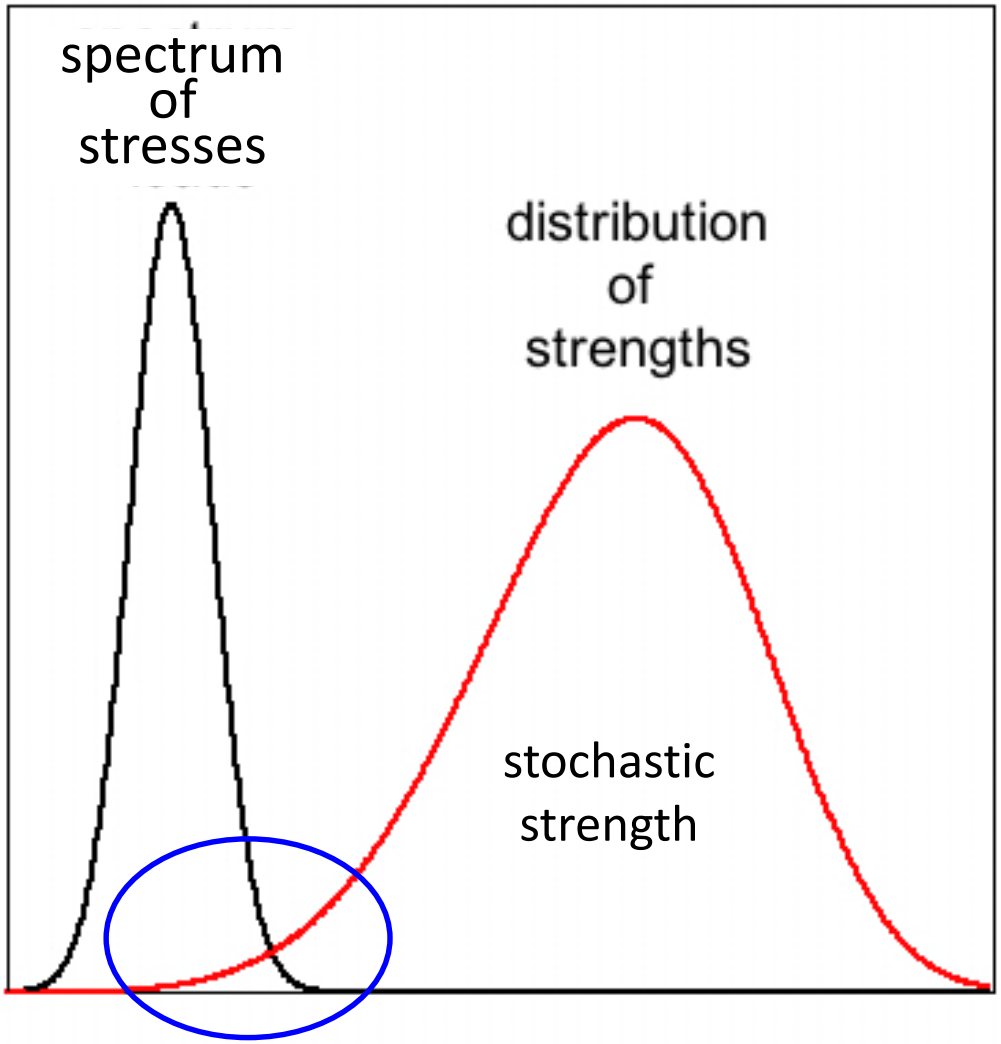
Failure, Reliability and Durability of Systems

The failure rate of complex systems can be described by the bathtub curve

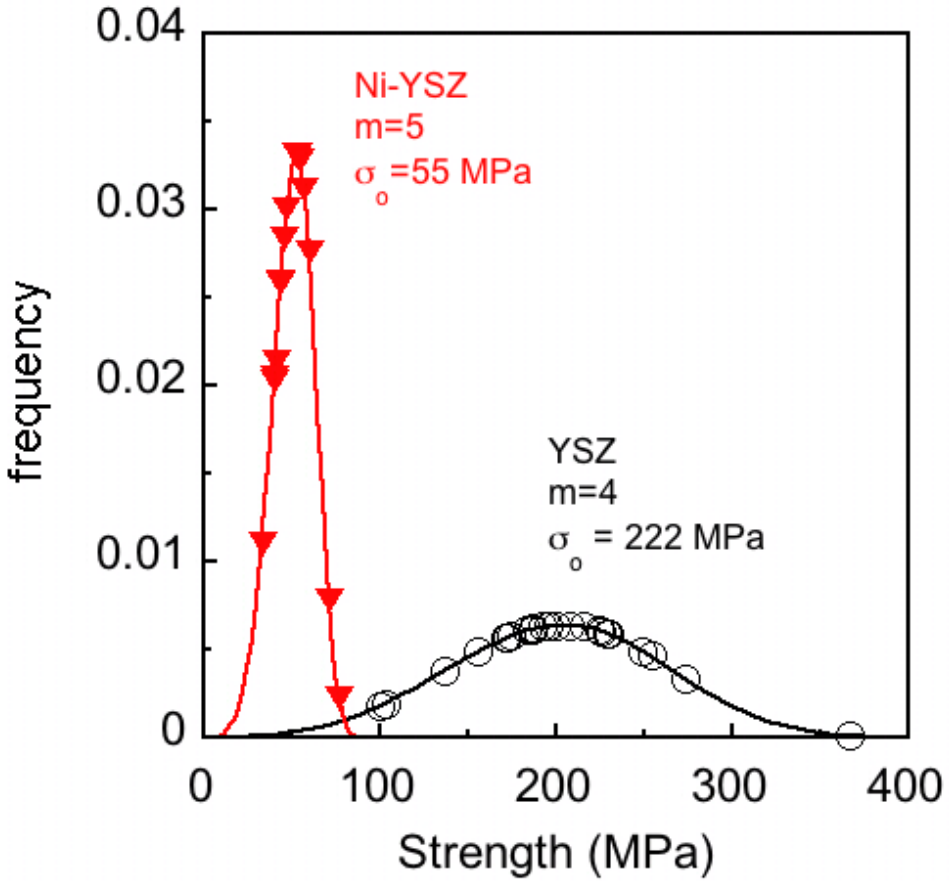


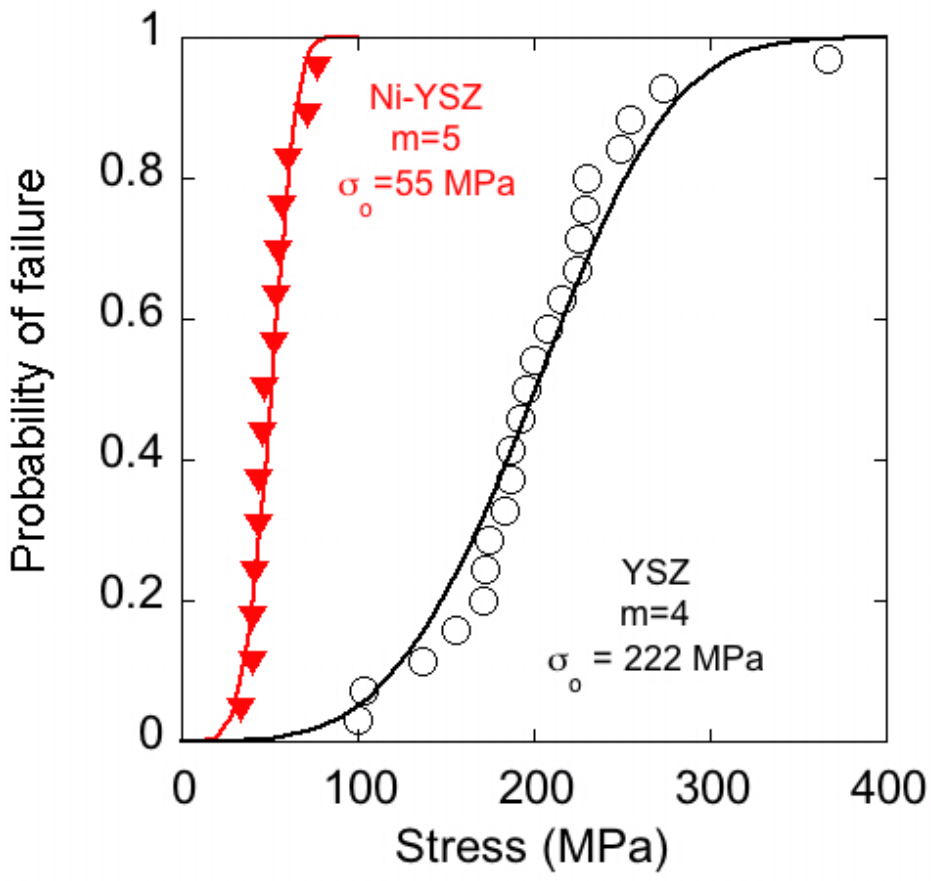
Failure, Reliability and Durability of Systems

- Failure is determined by the intersection of the distributions of loads and strengths.
- The weakest elements of the population determine the reliability of the system.



Strength of SOFC materials





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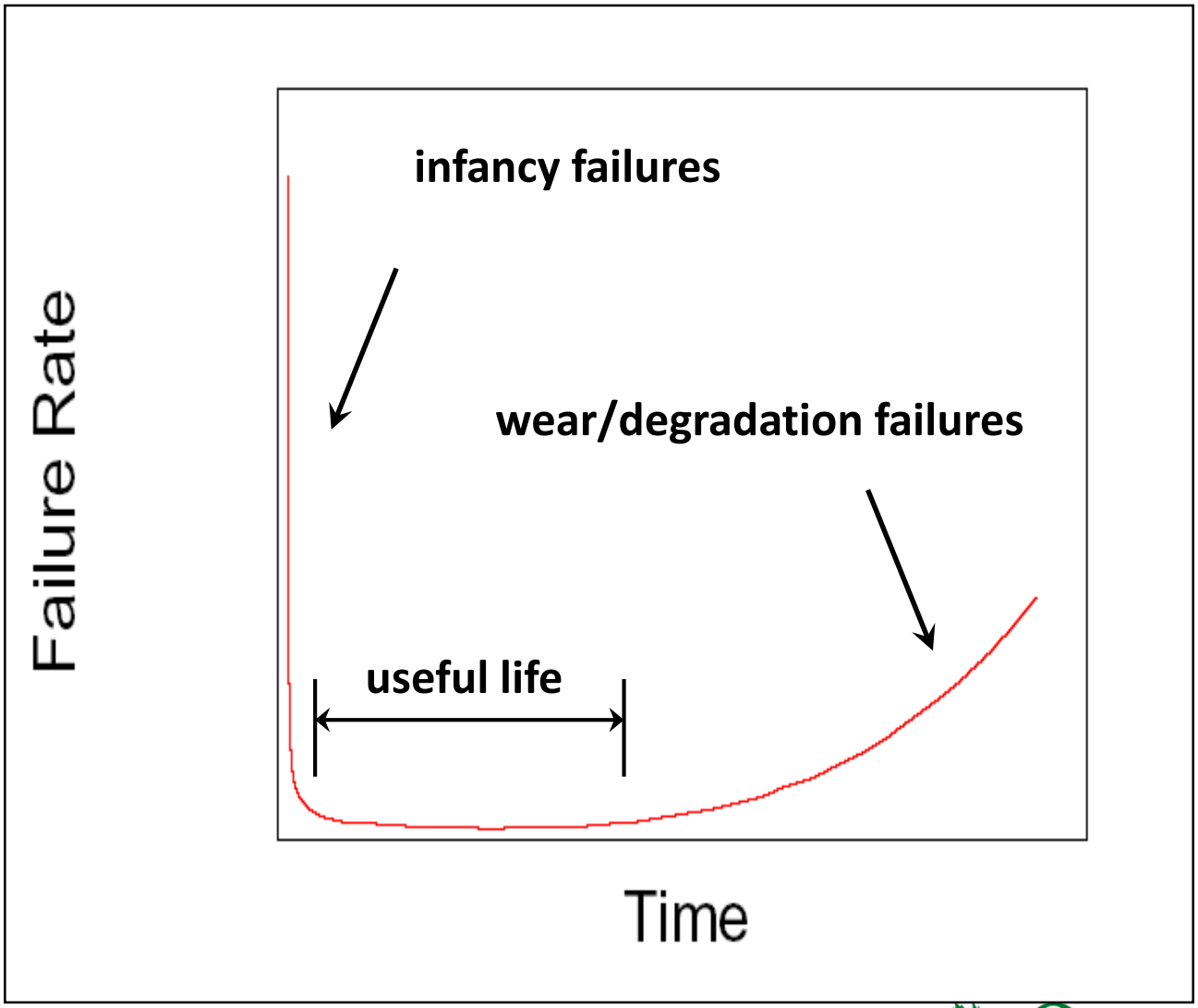

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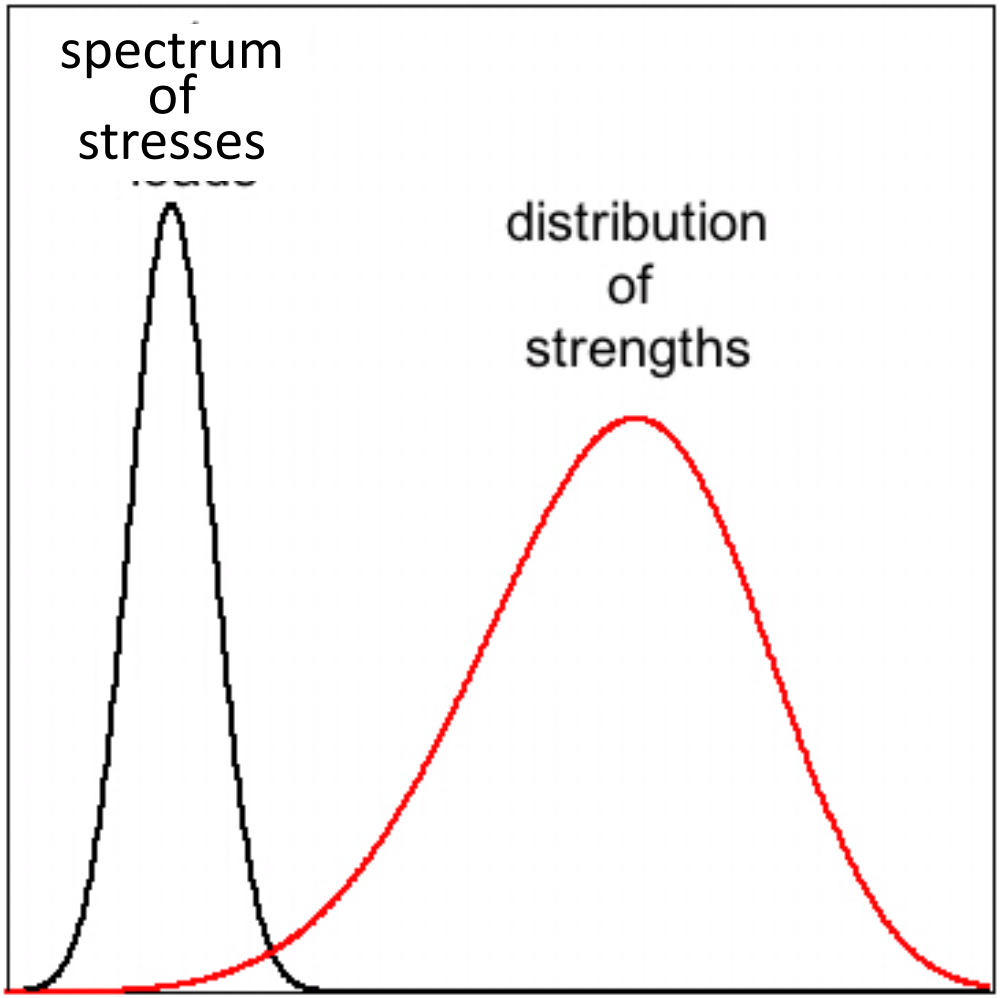

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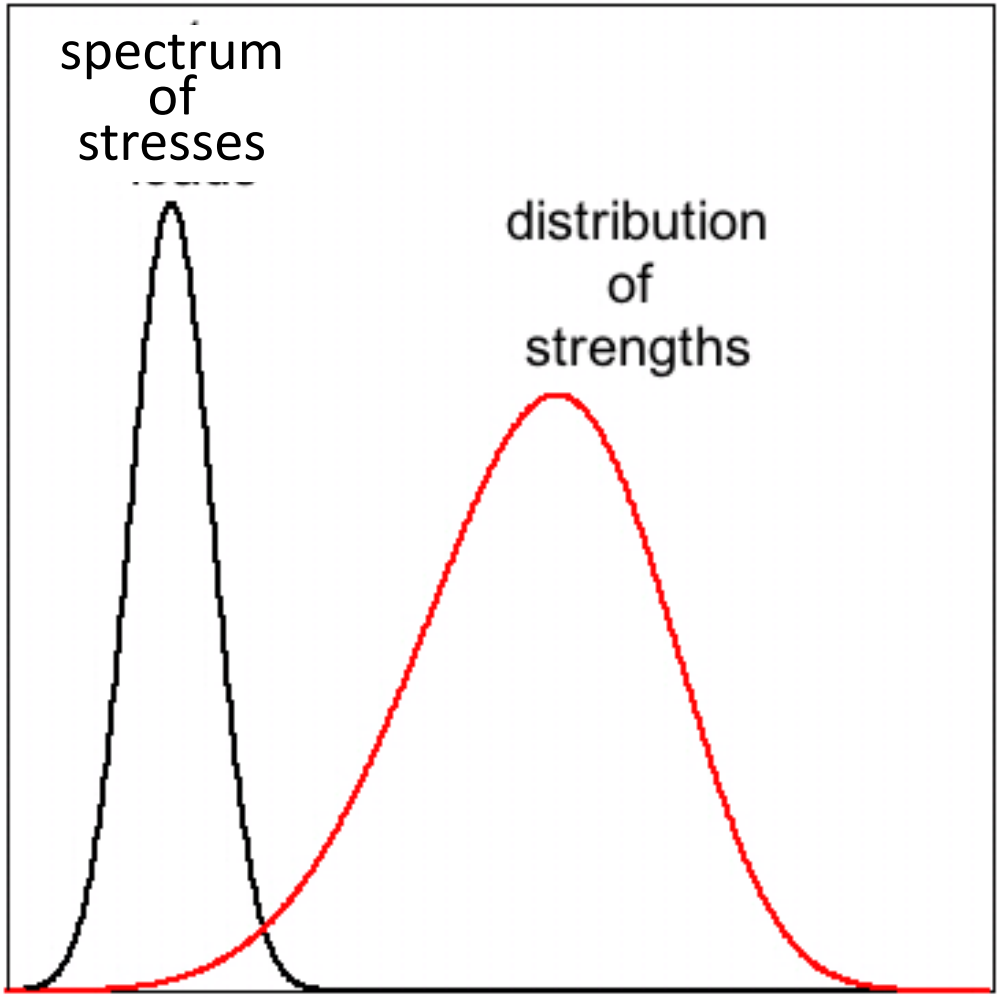

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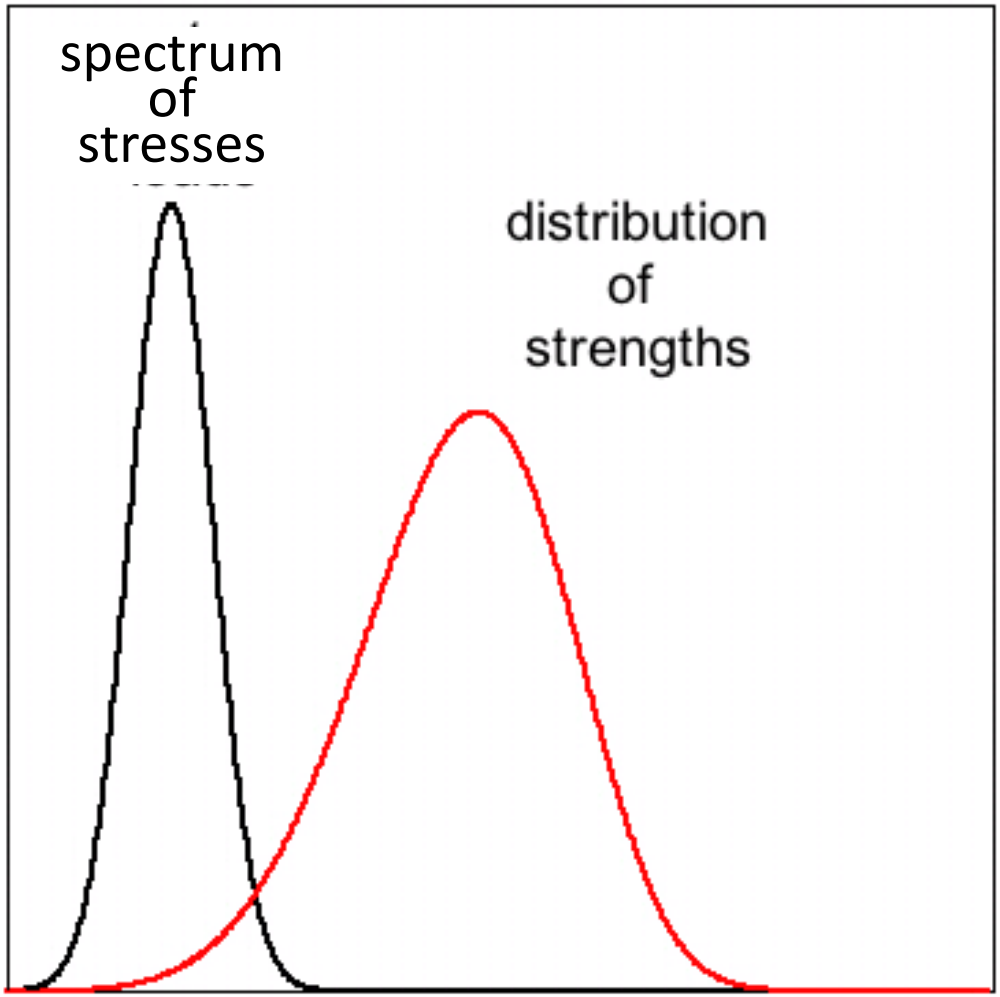

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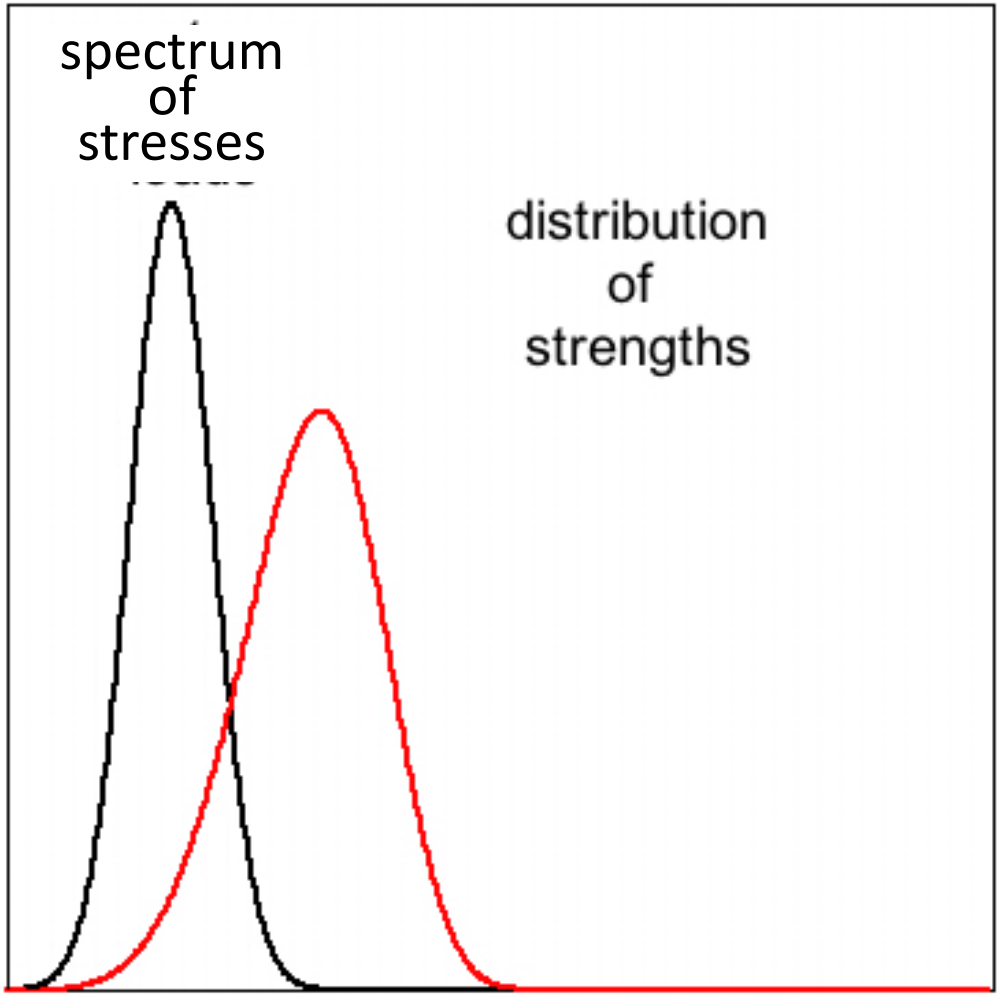

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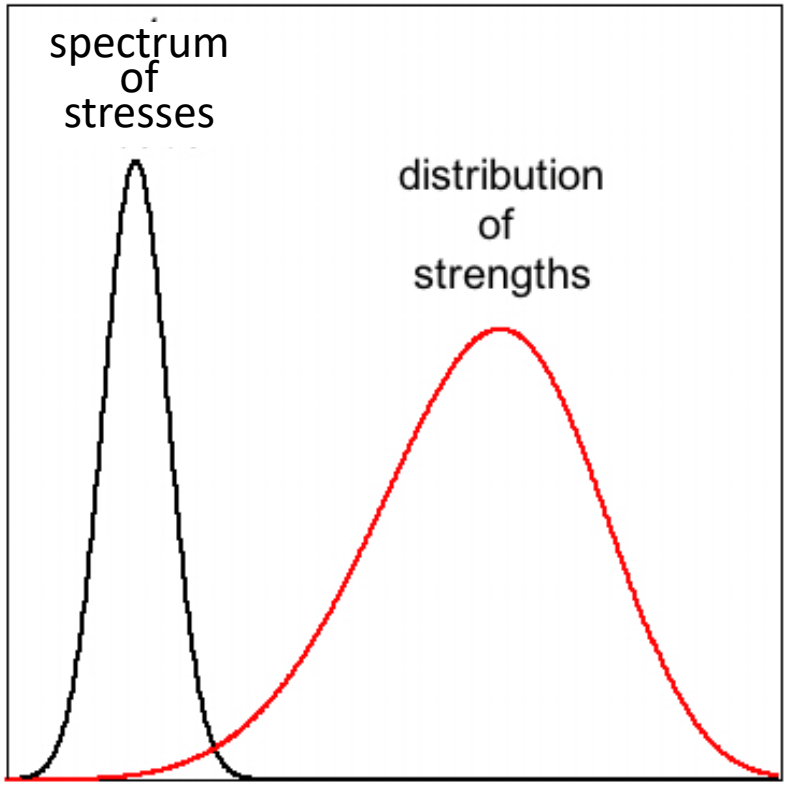
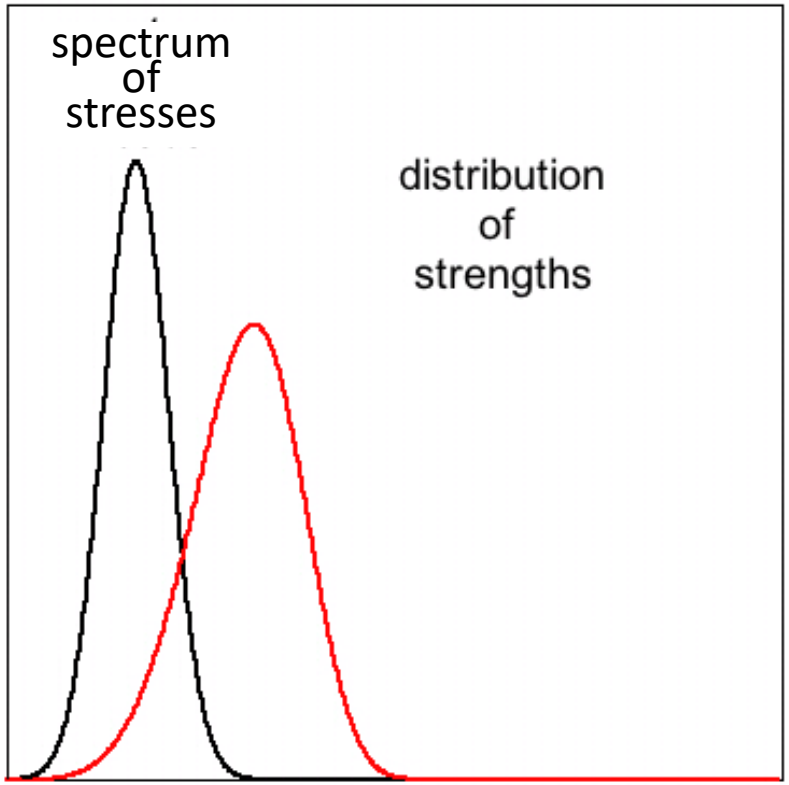


before



after

Background

- The reliability and durability of materials and components for solid-oxide fuel cells is determined by their state of stress, which consists of the superposition of:
  - Residual stresses
  - Assembly stresses
  - Operational stresses
- Ni-YSZ exhibits creep deformation at temperatures relevant to the operation of SOFCs

Questions

- Does creep deformation change the microstructure of anode materials?
  - If yes, how do these changes affect the functionality of the anode?
- If the layers bonded to the anode in a cell (e.g., electrolyte and interconnect) have greater creep resistance than the anode, how do stresses experienced by the anode get redistributed to the neighboring layers during SOFC operation?

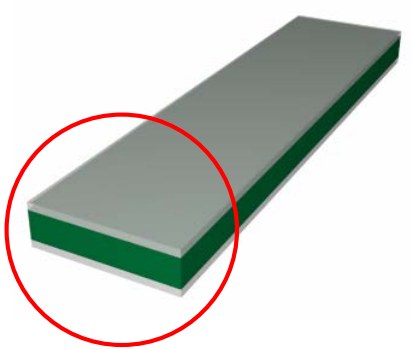
Objective

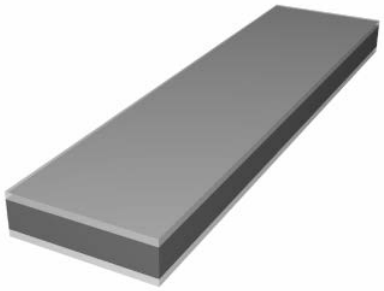
To understand the effect of creep deformation of anode materials on its microstructure and on the redistribution of stresses in SOFCs, and to determine the implications on their durability and reliability

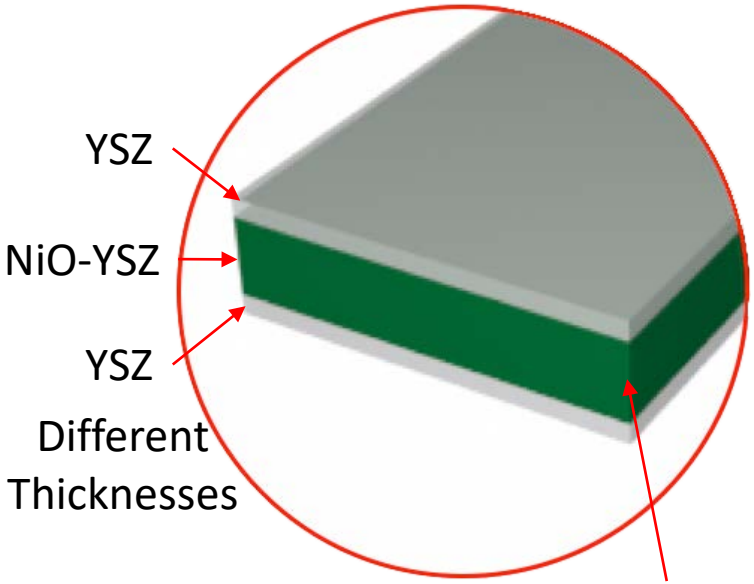
Materials (Sandwich Configuration)

As-processed

After reduction

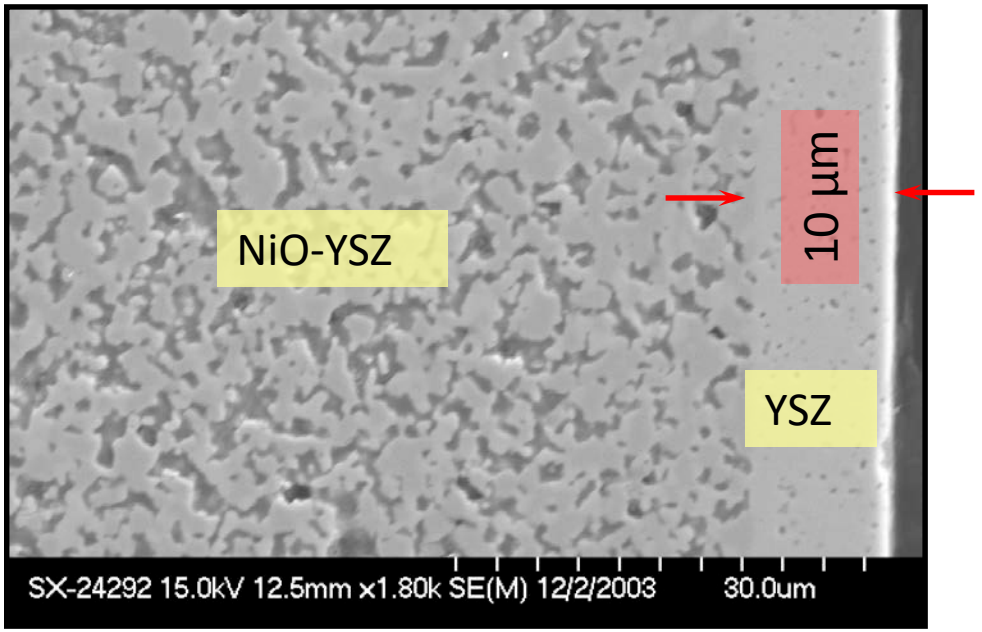






Different Thicknesses

Porosity
15%
30%
40%



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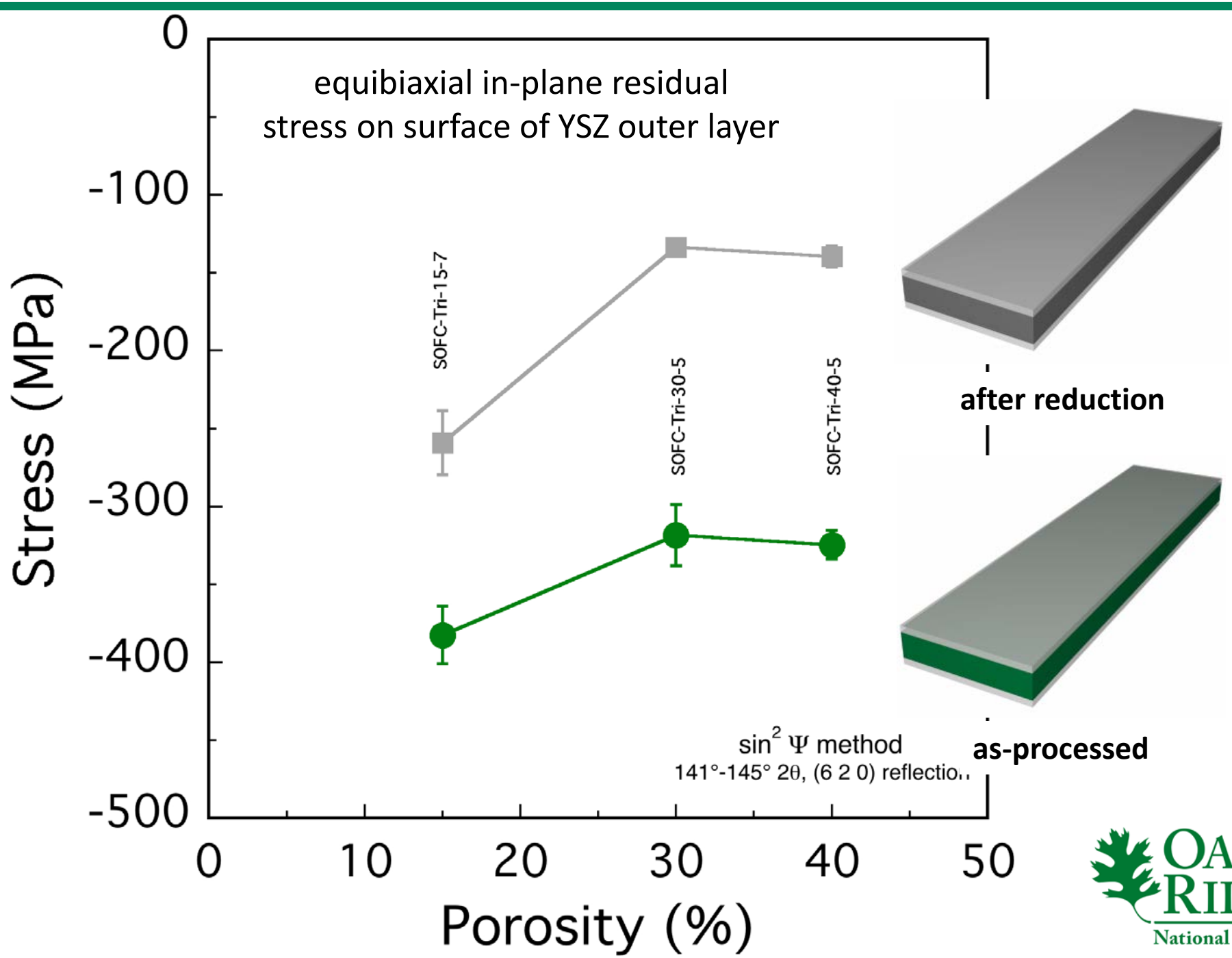
Residual Stresses

Measurements obtained on surface of YSZ layer by X-ray diffraction



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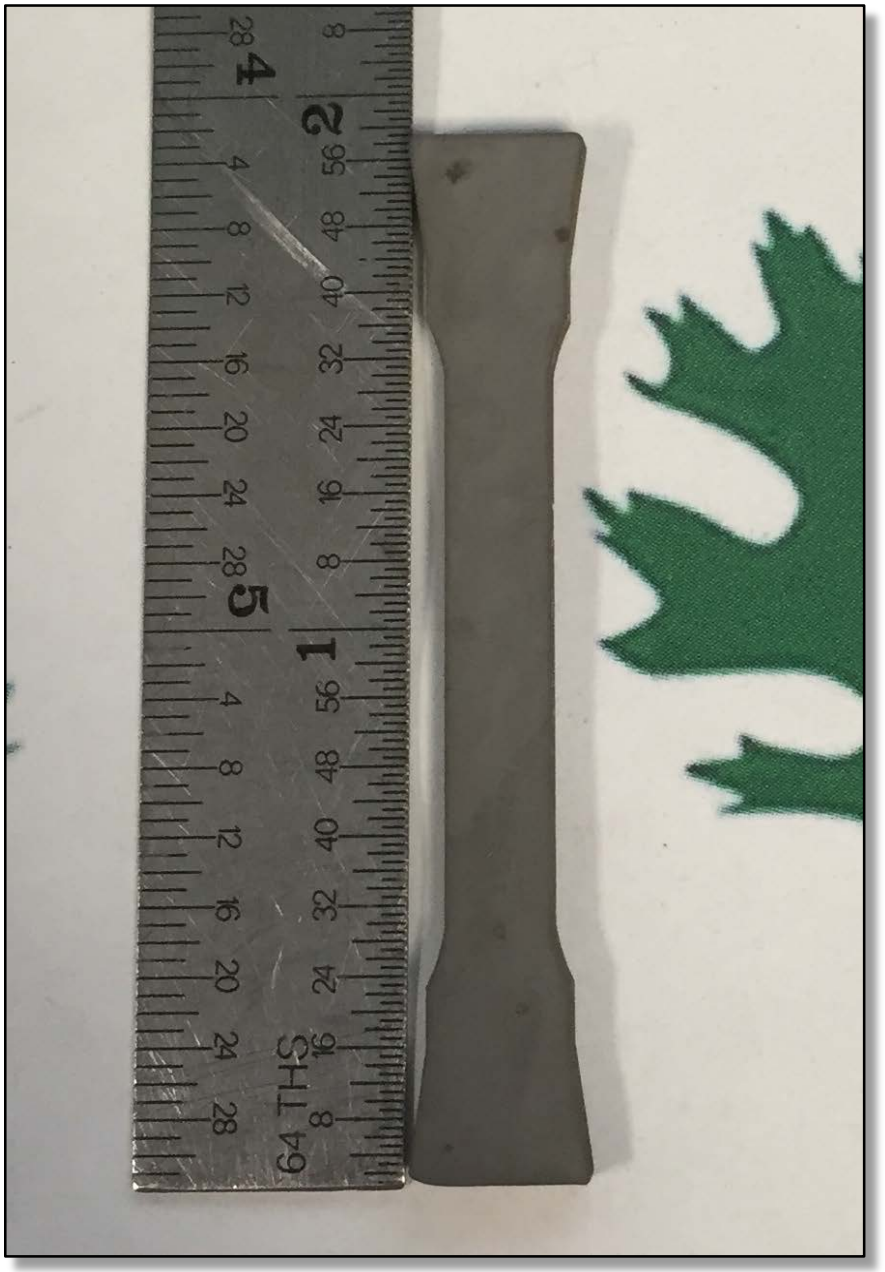
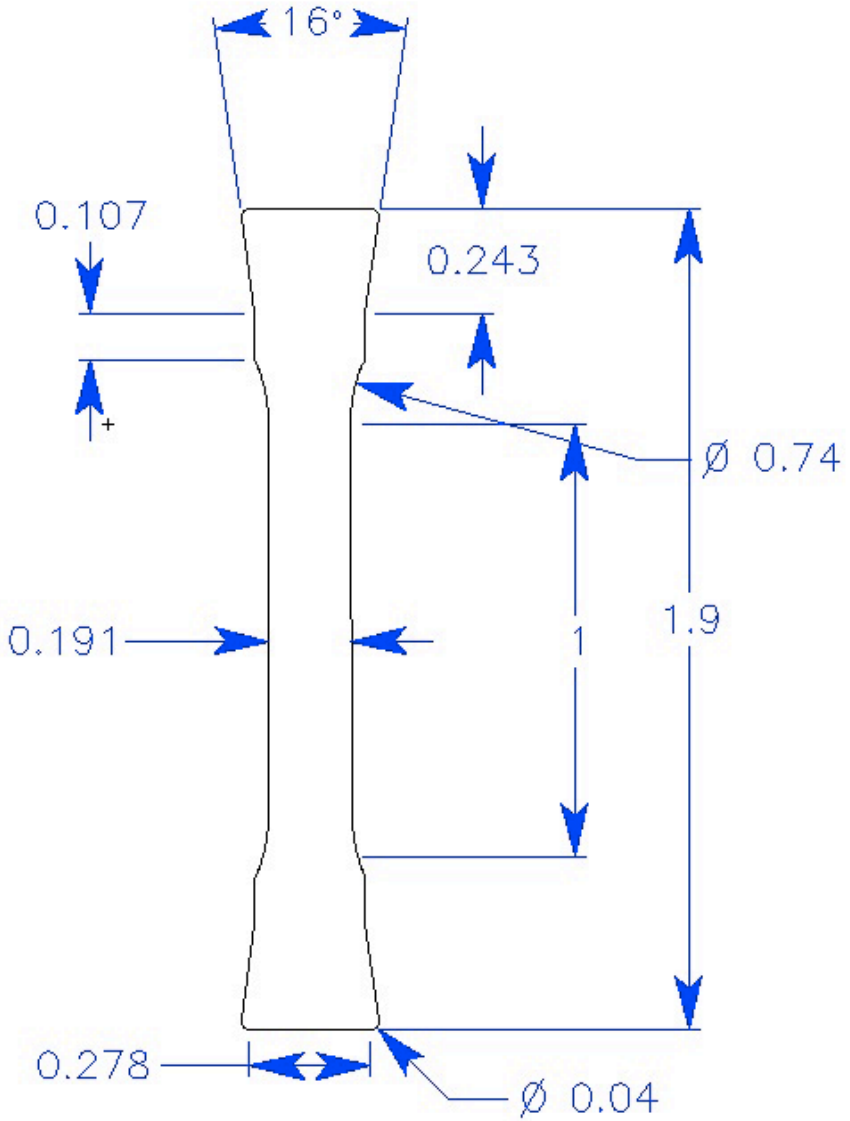
Shoulder-loaded Tensile Specimen





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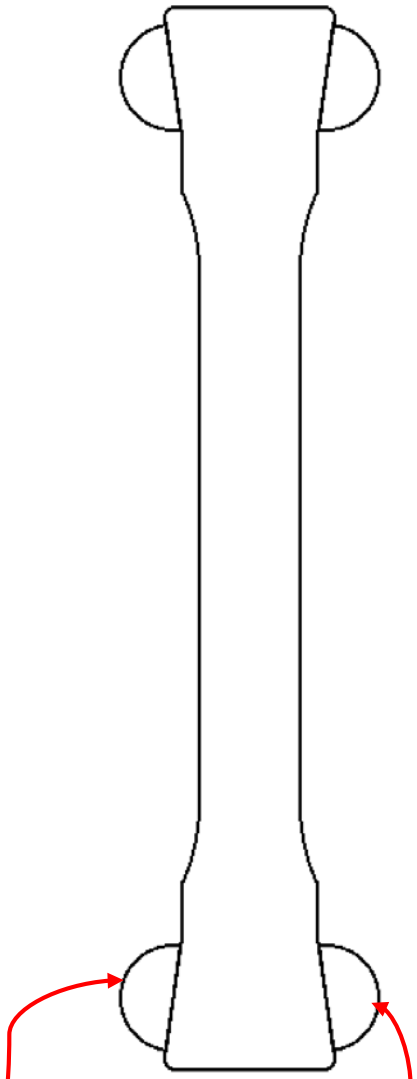
Creep Testing Facility

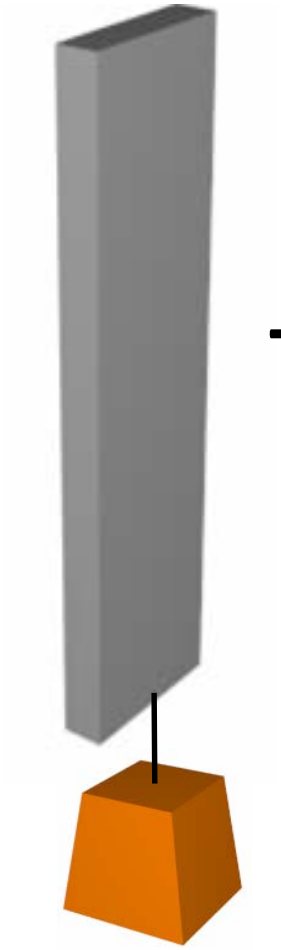


Load is transferred to the test specimen through its shoulders

Creep Testing Facility

- High temperature
- Controlled environment

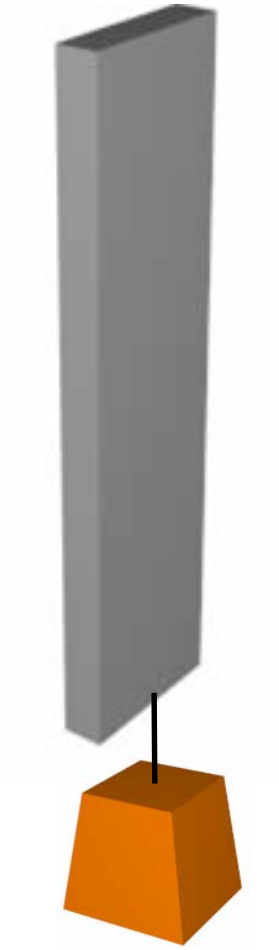
Creep Deformation

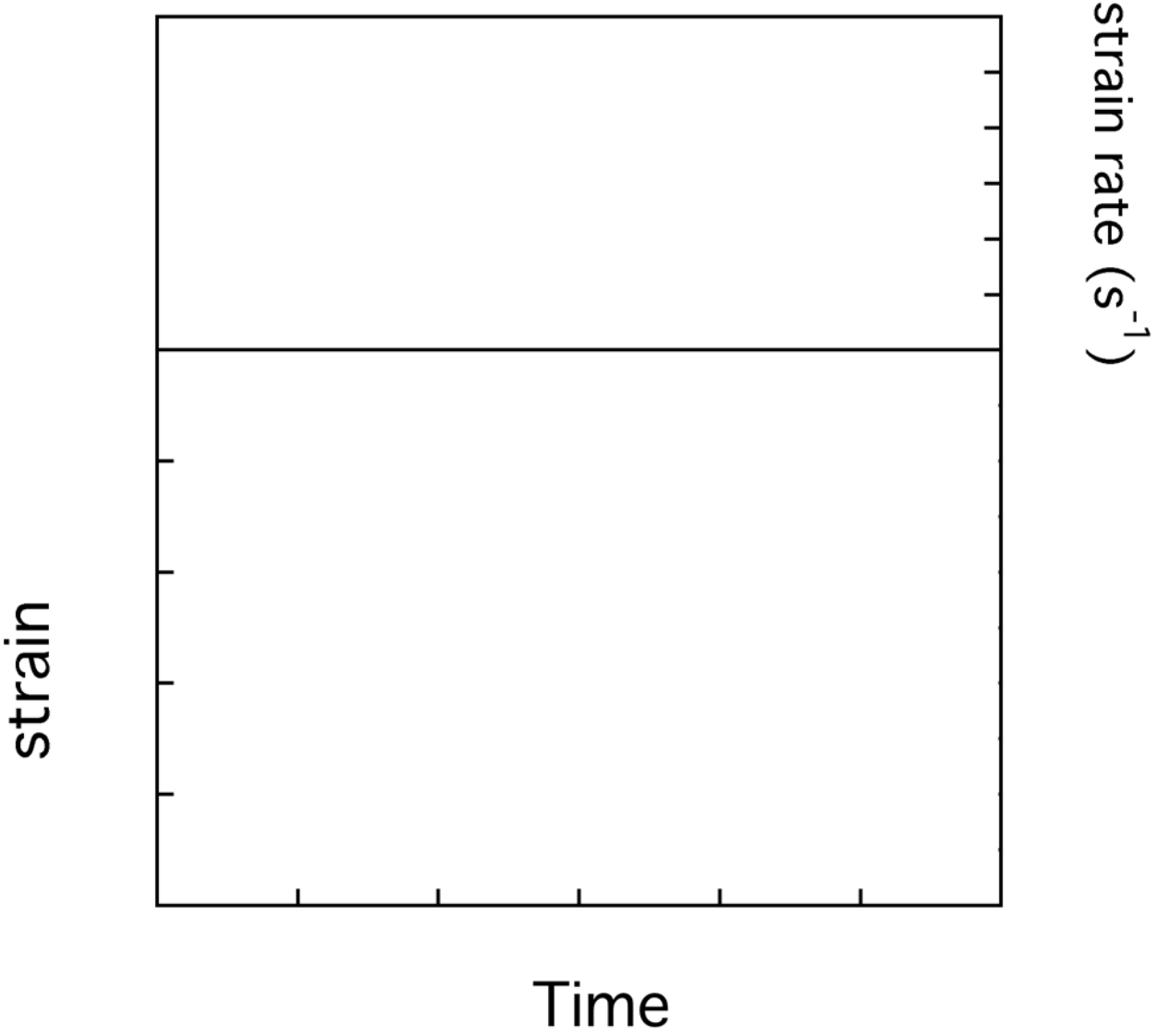


Test Specimen

Constant Stress

Creep Deformation





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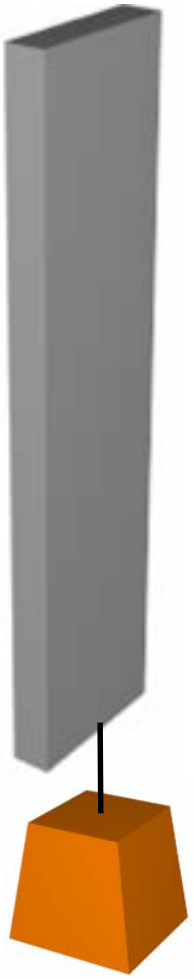

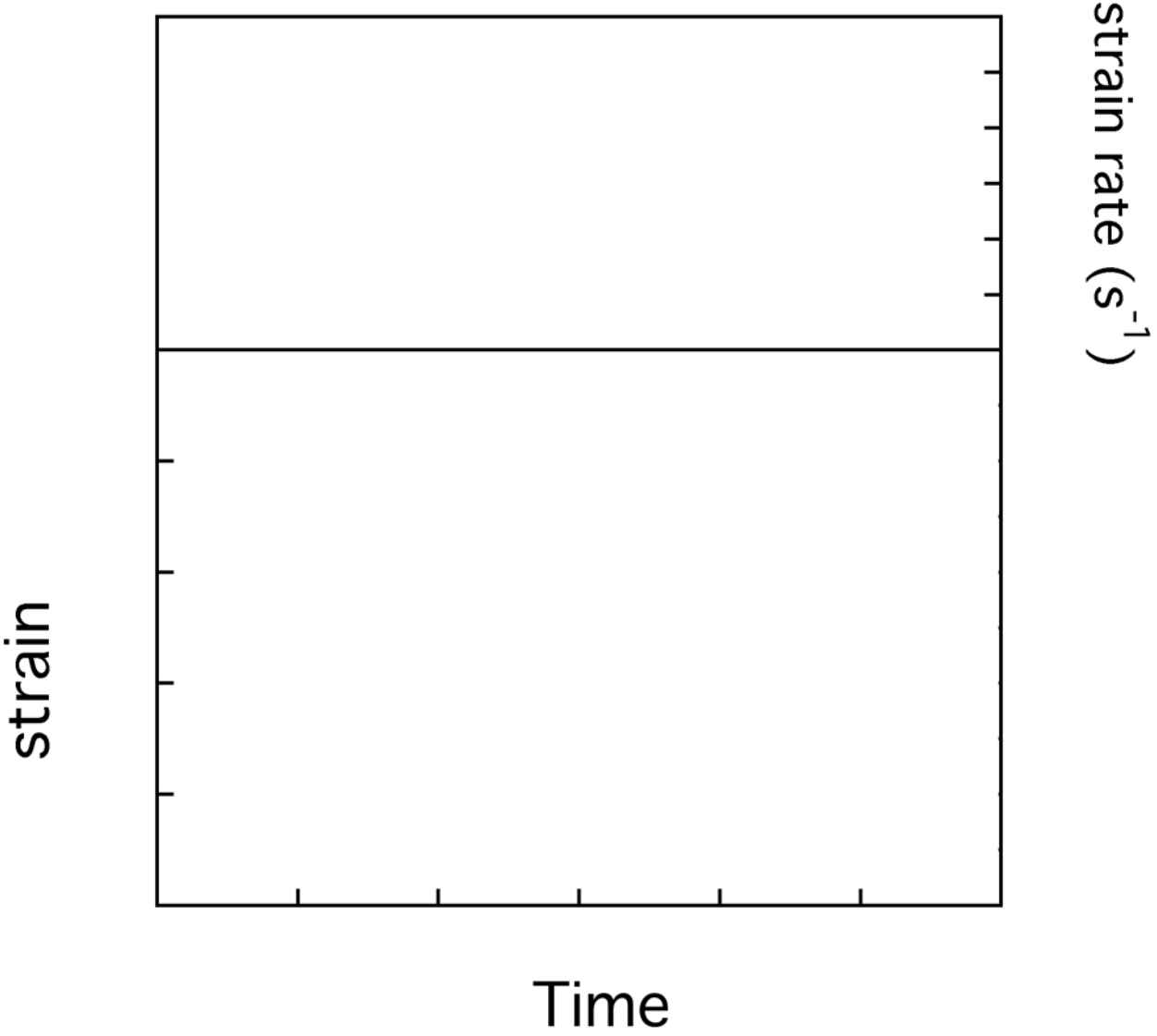

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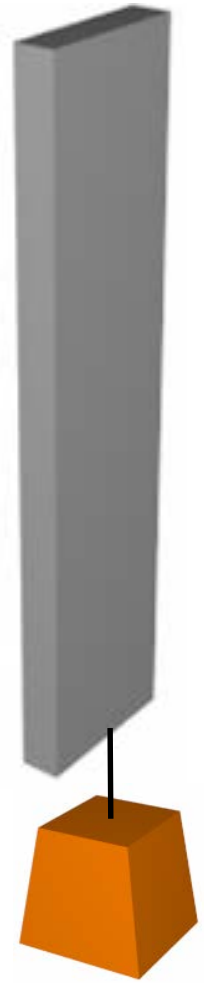

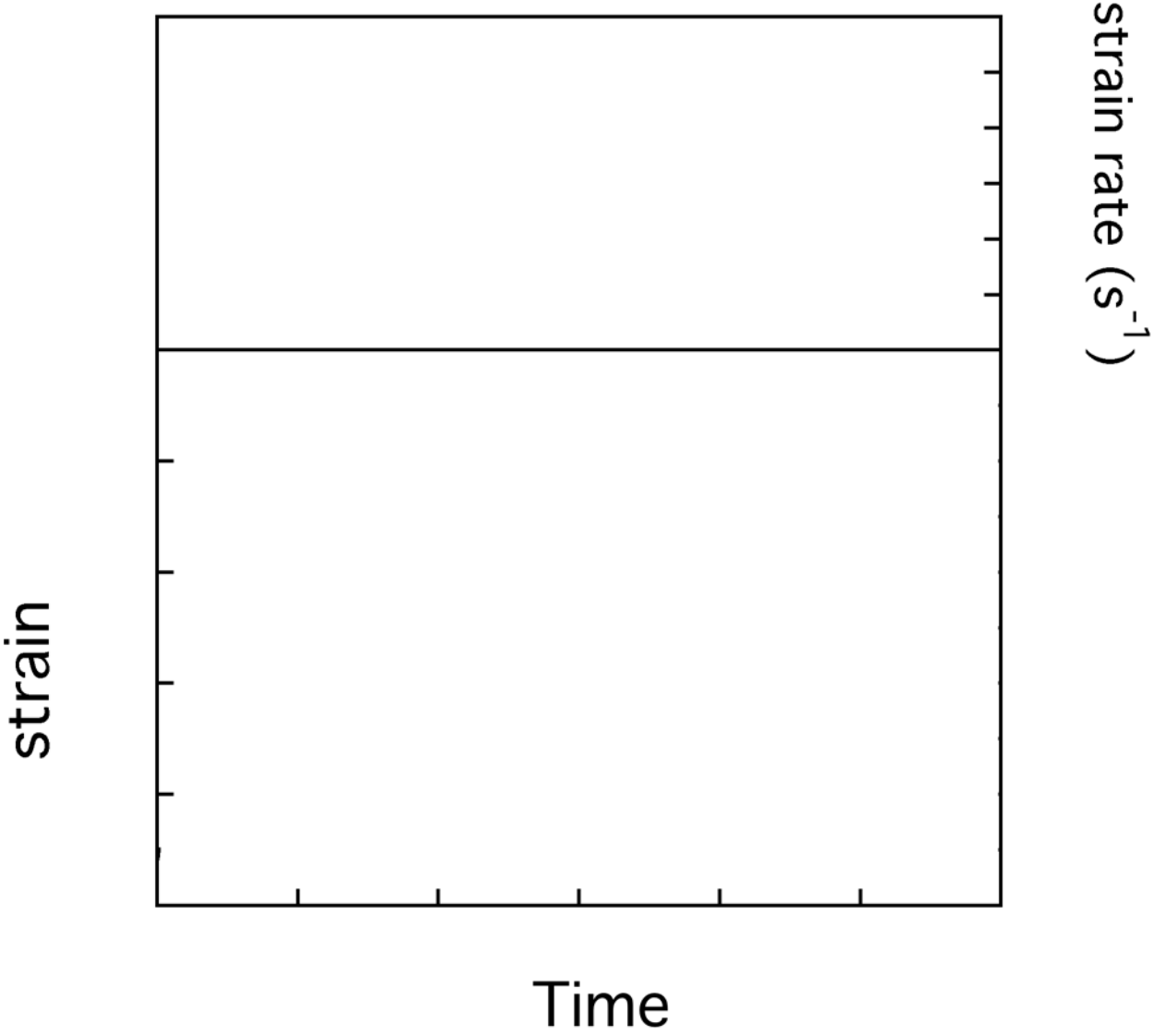

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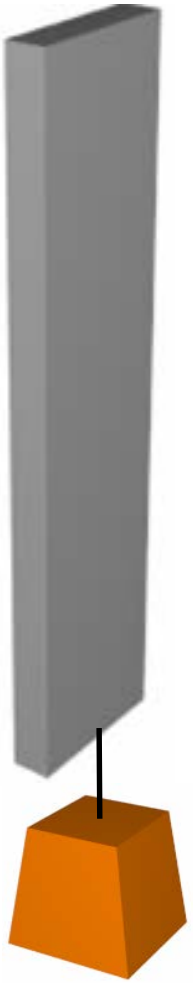

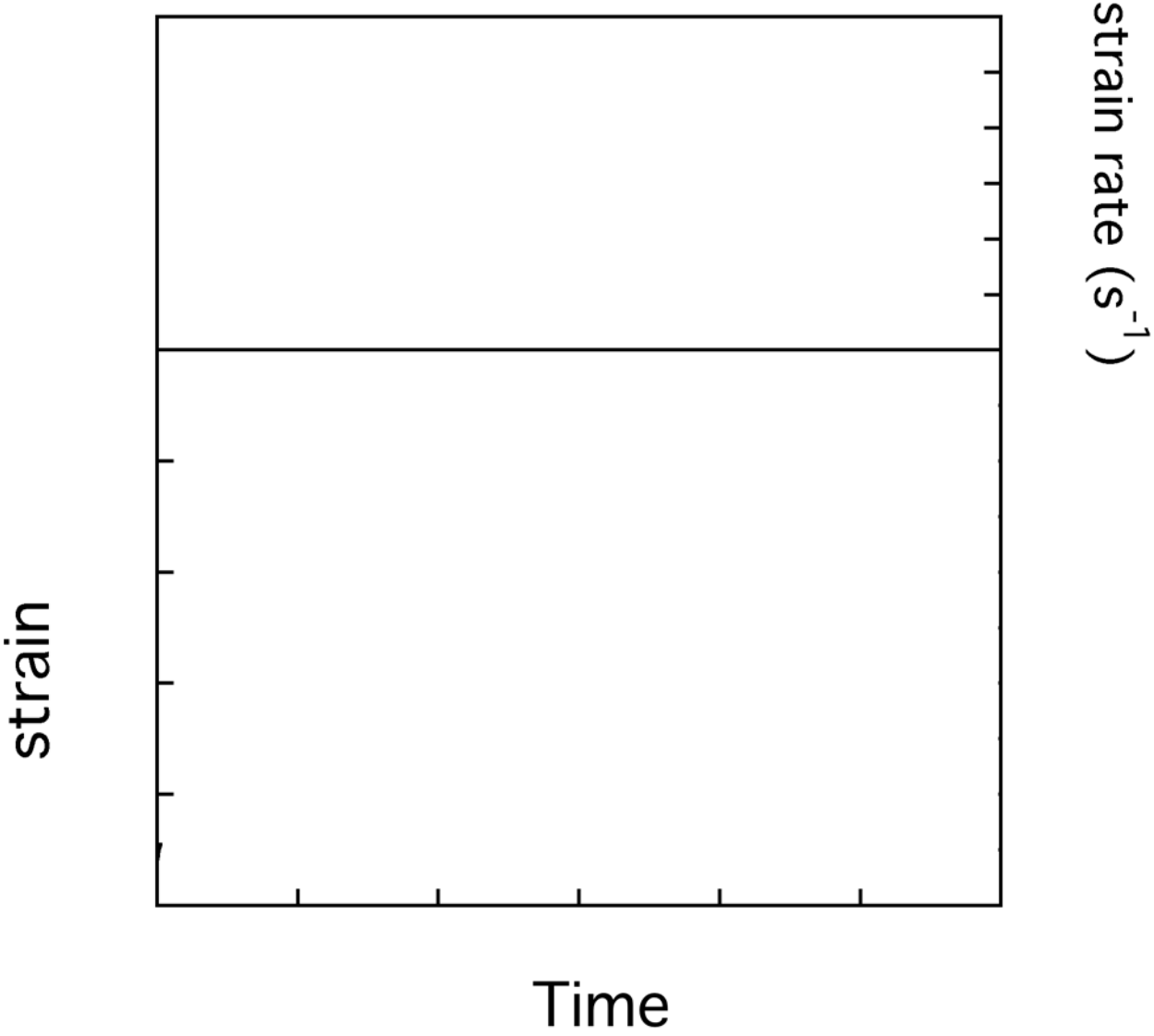

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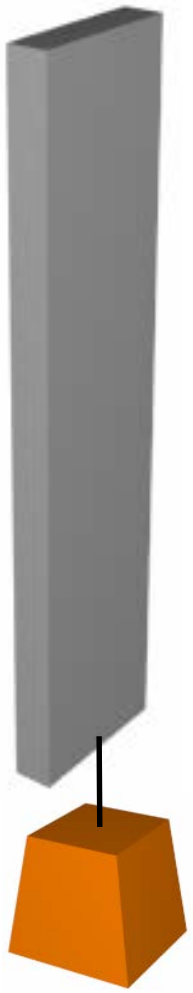

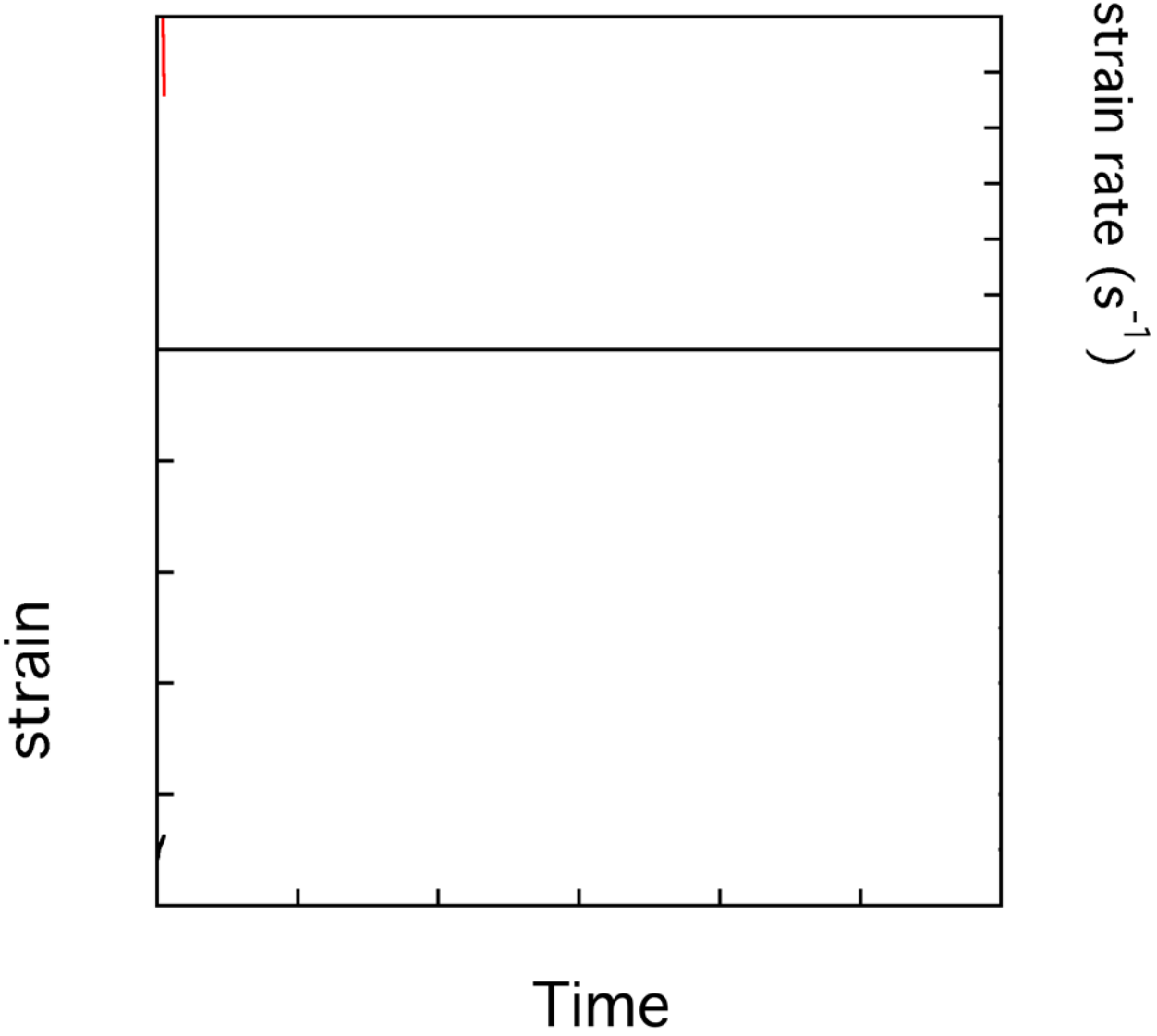

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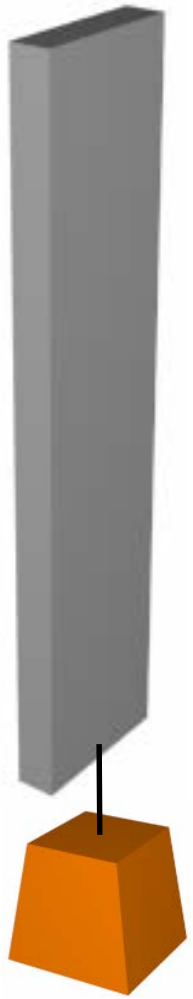

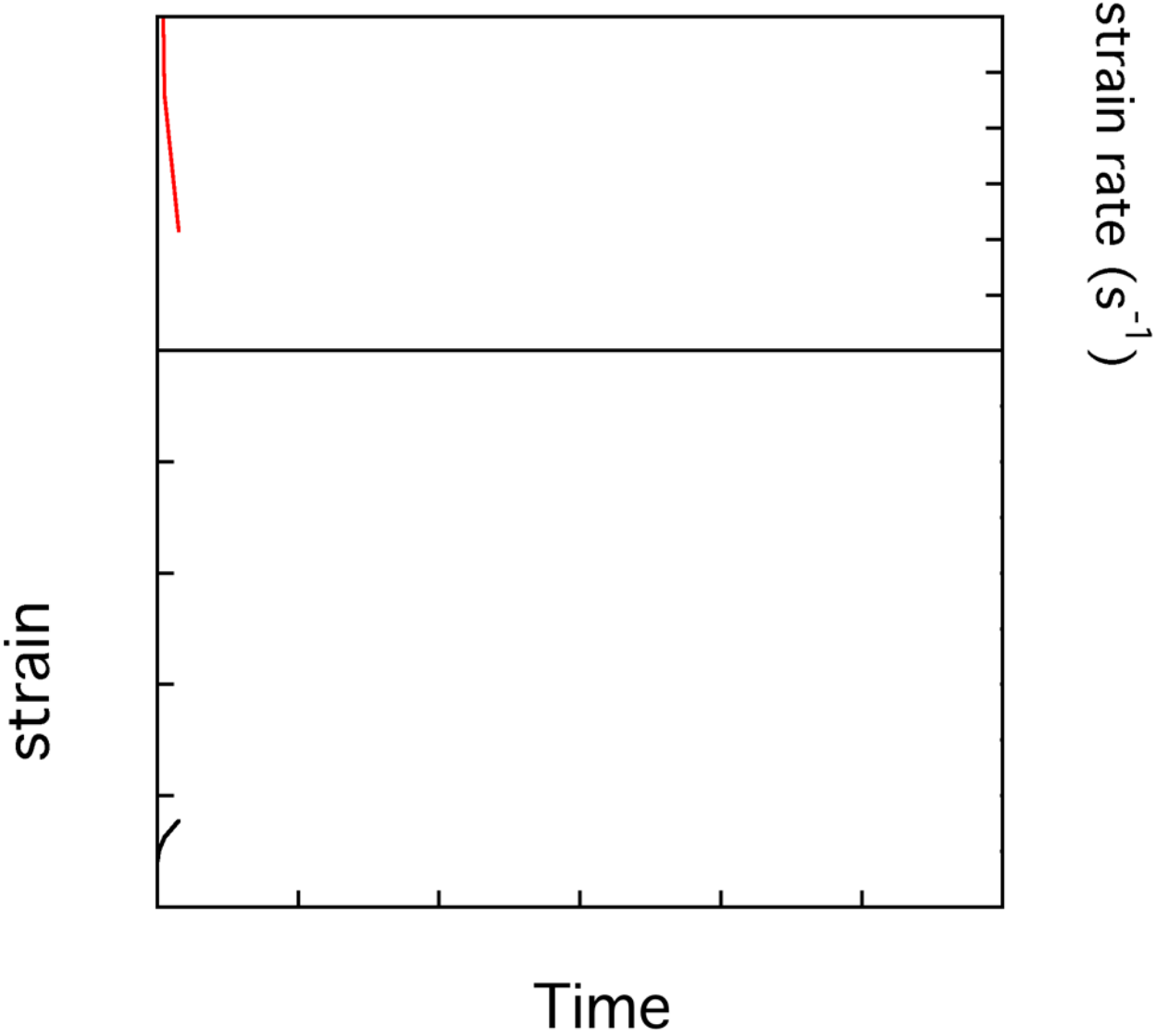

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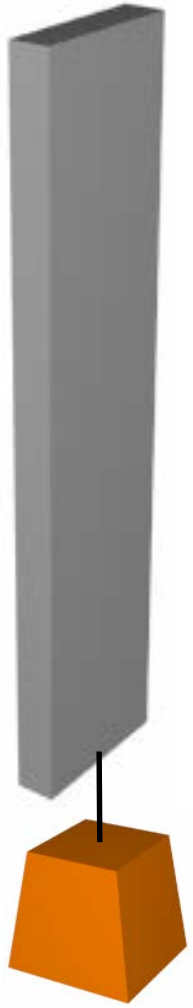

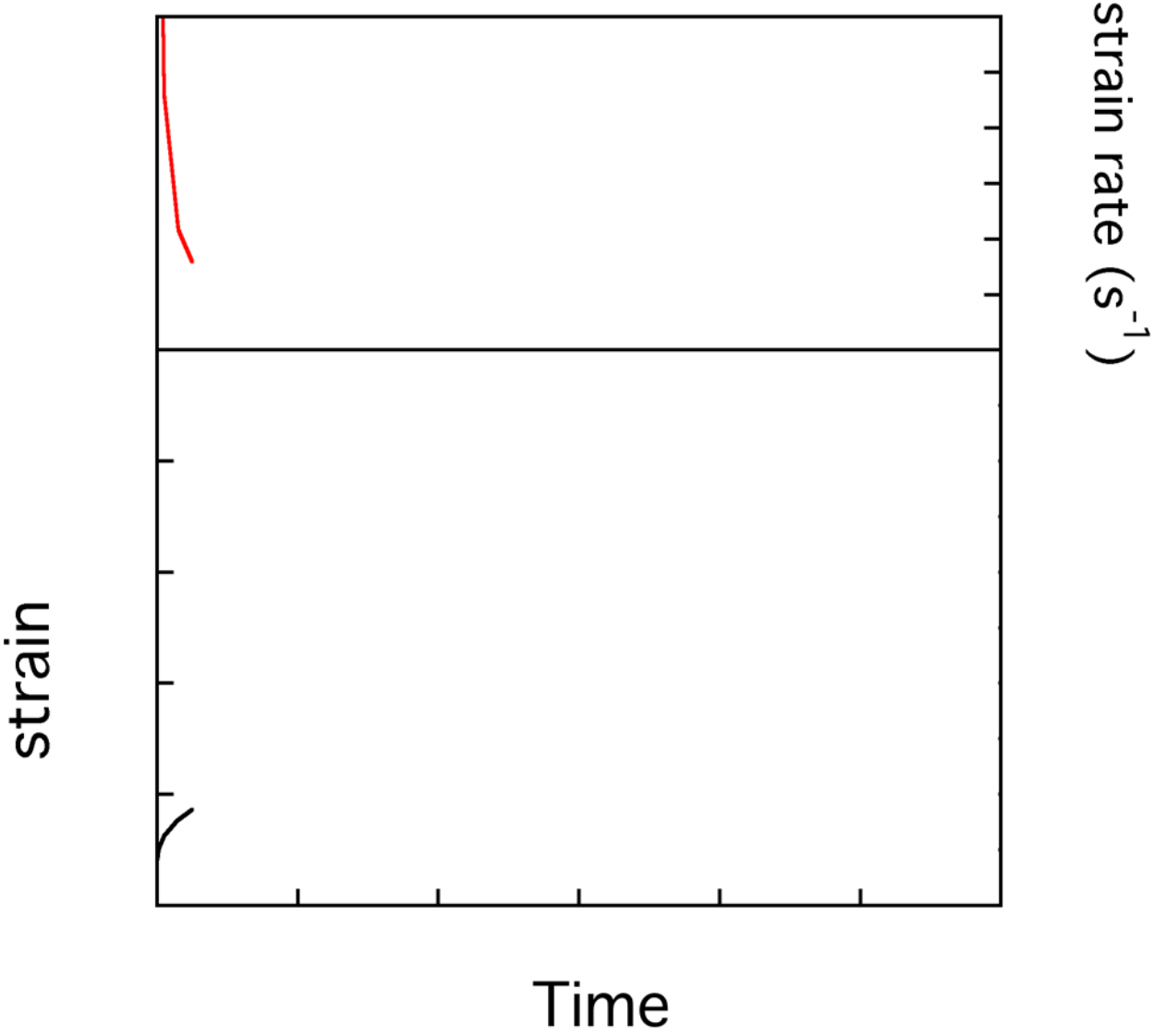

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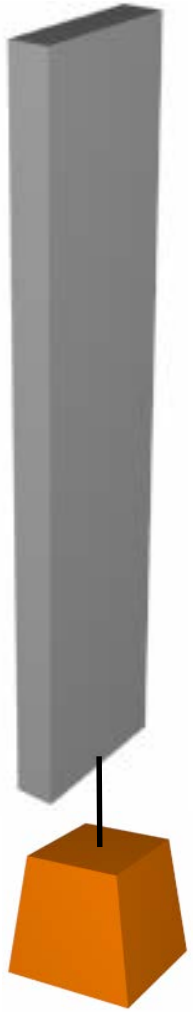

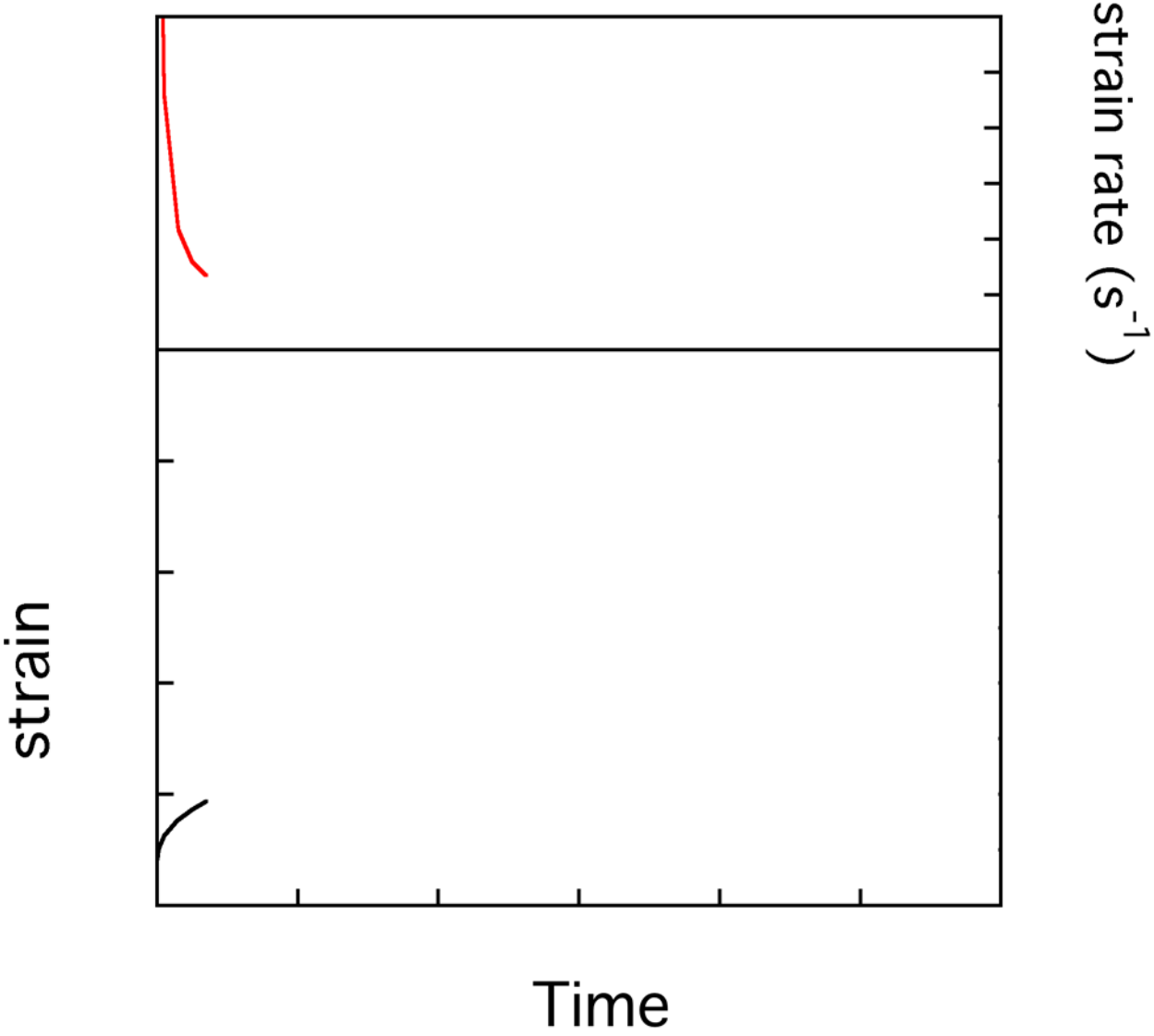

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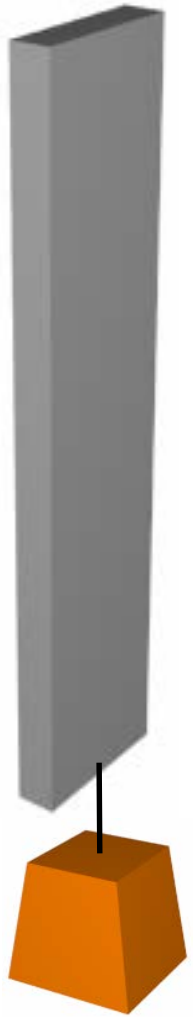

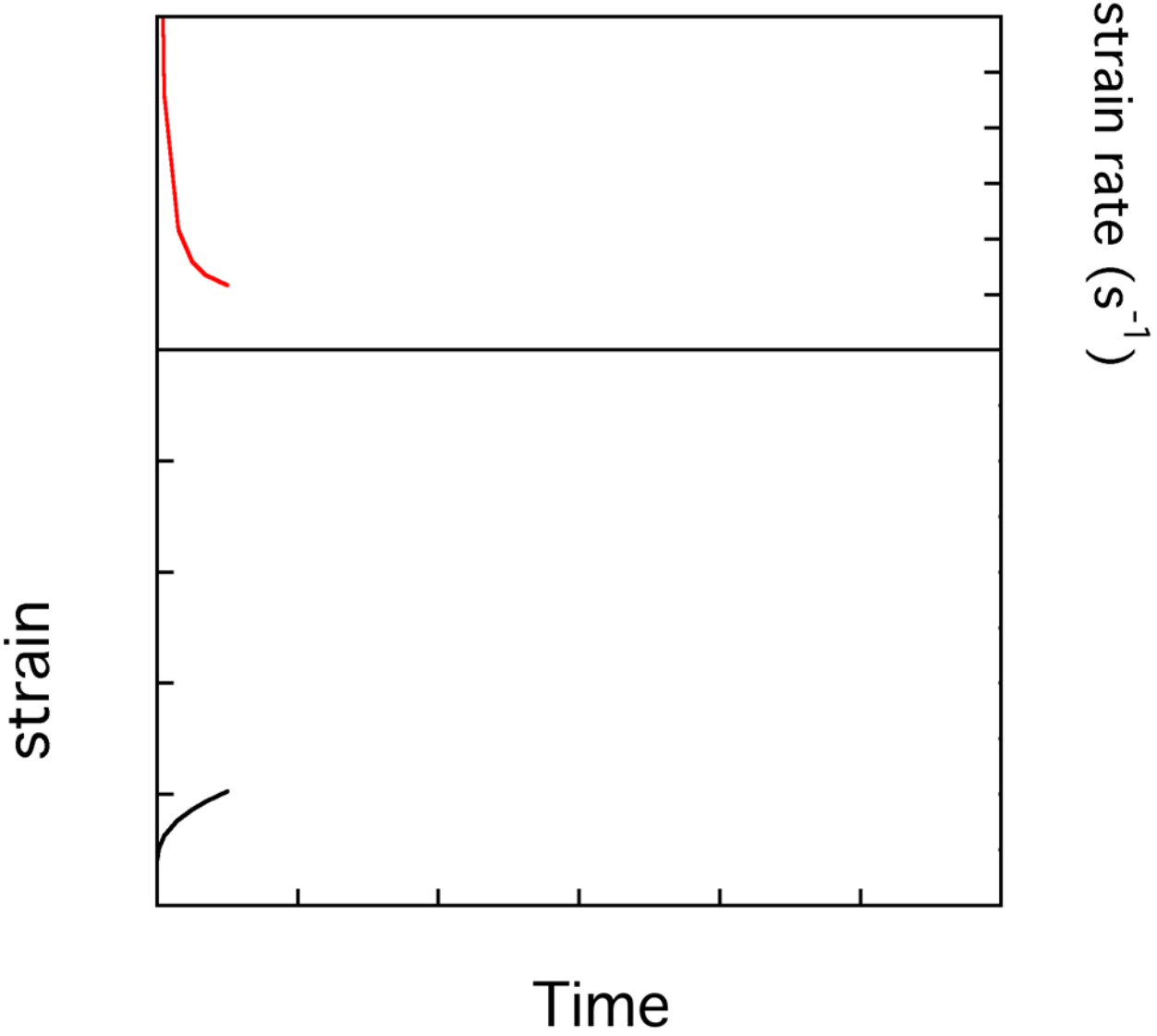

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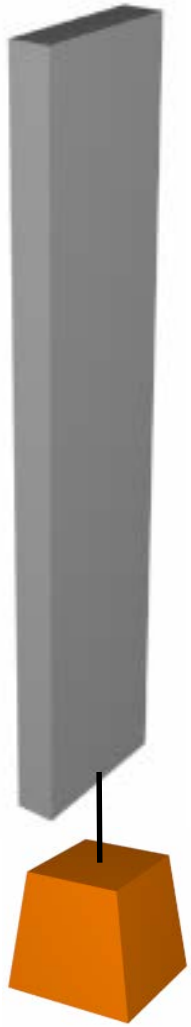

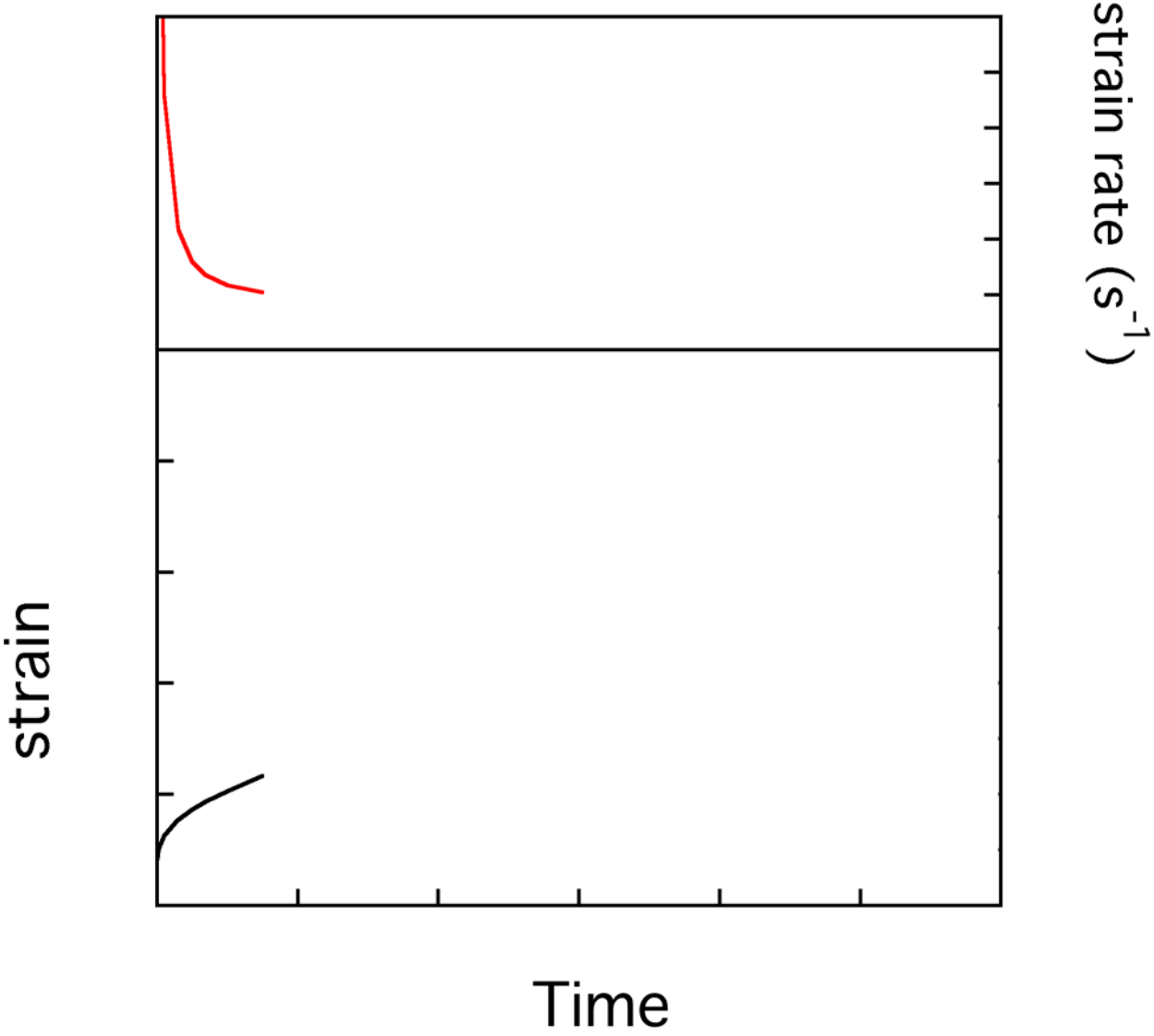

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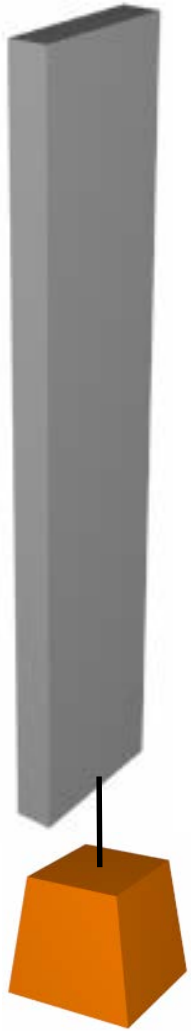

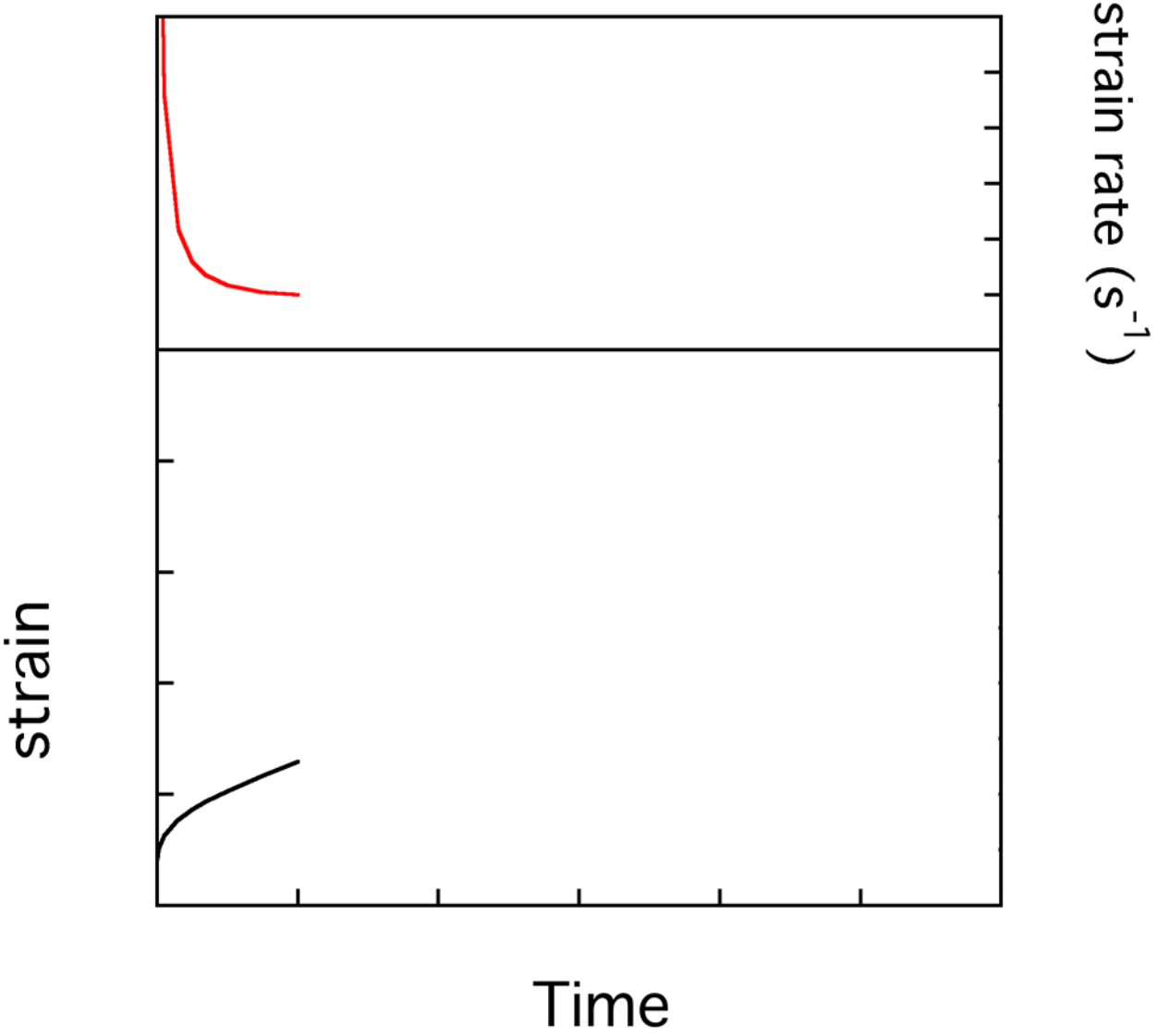

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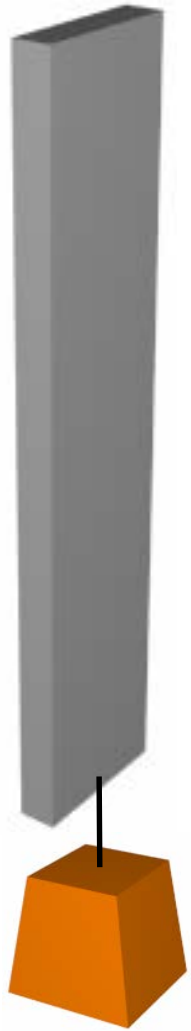

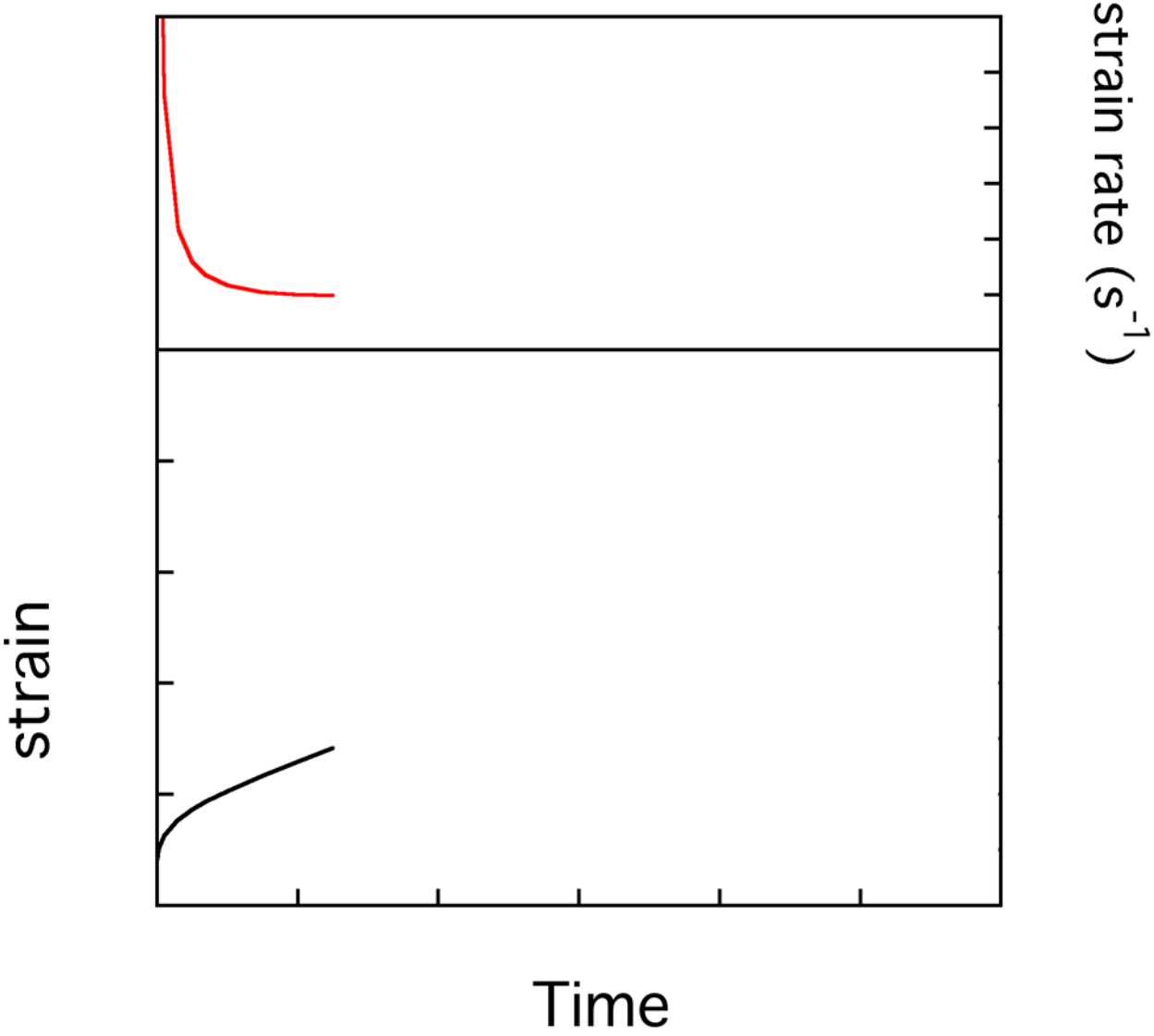

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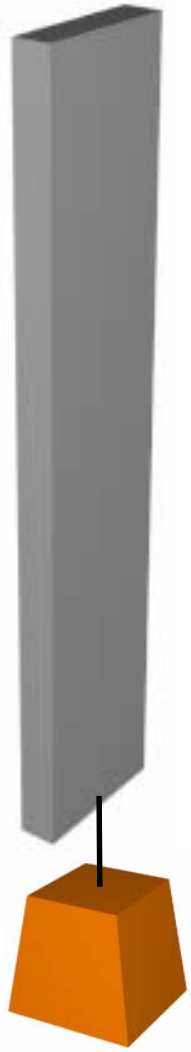

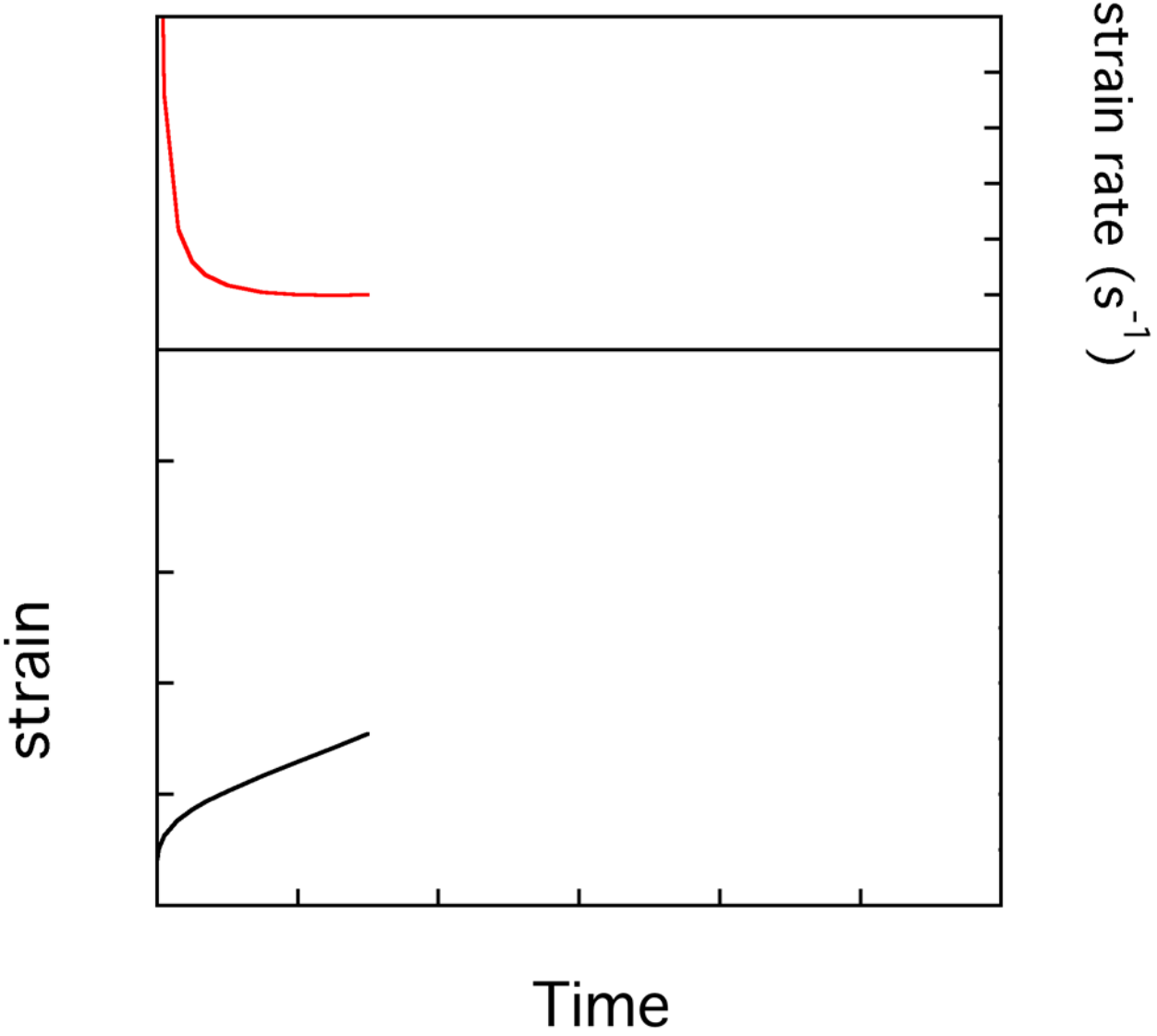

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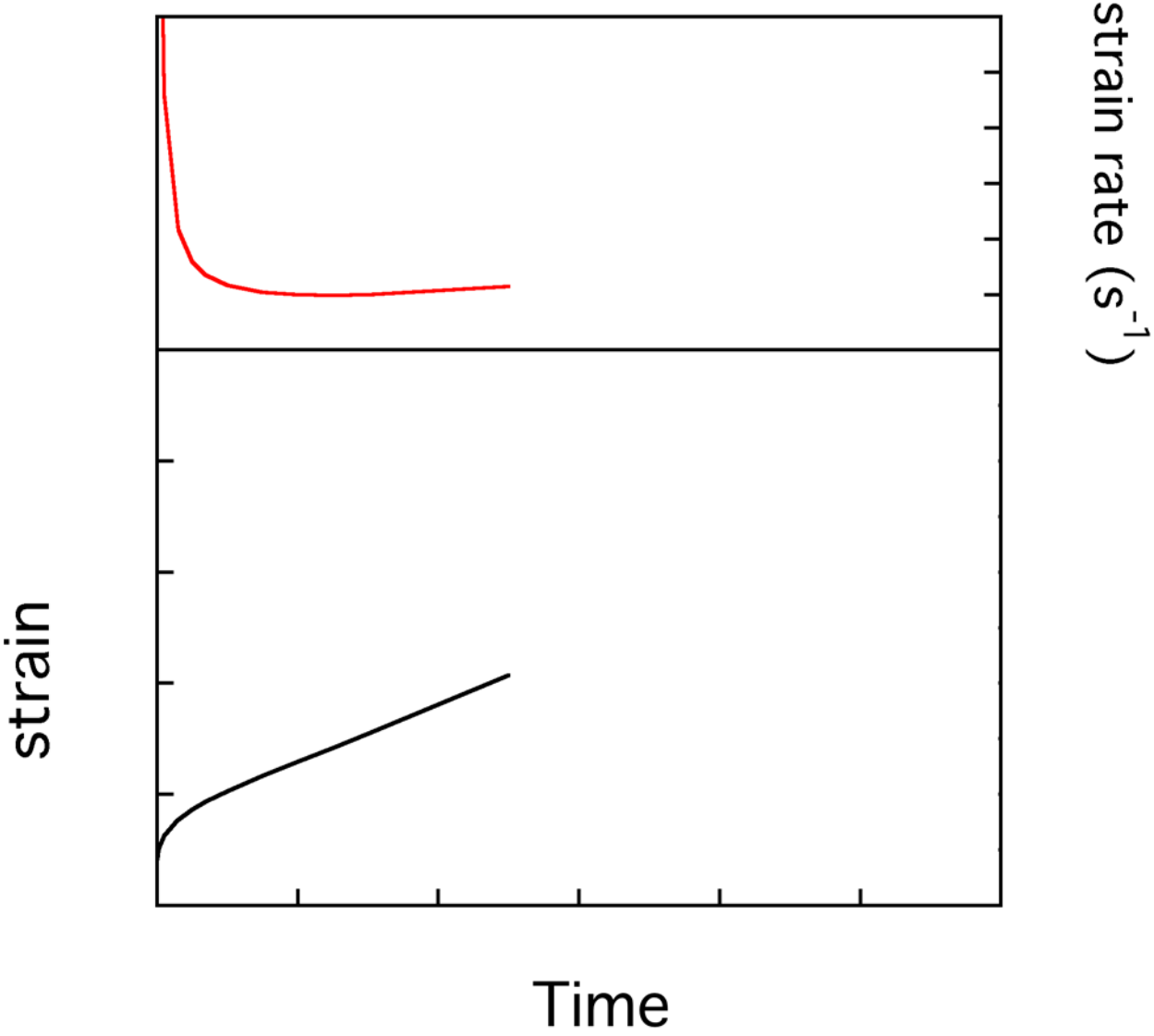

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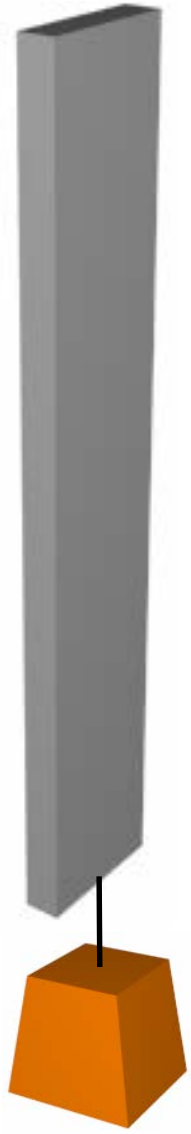

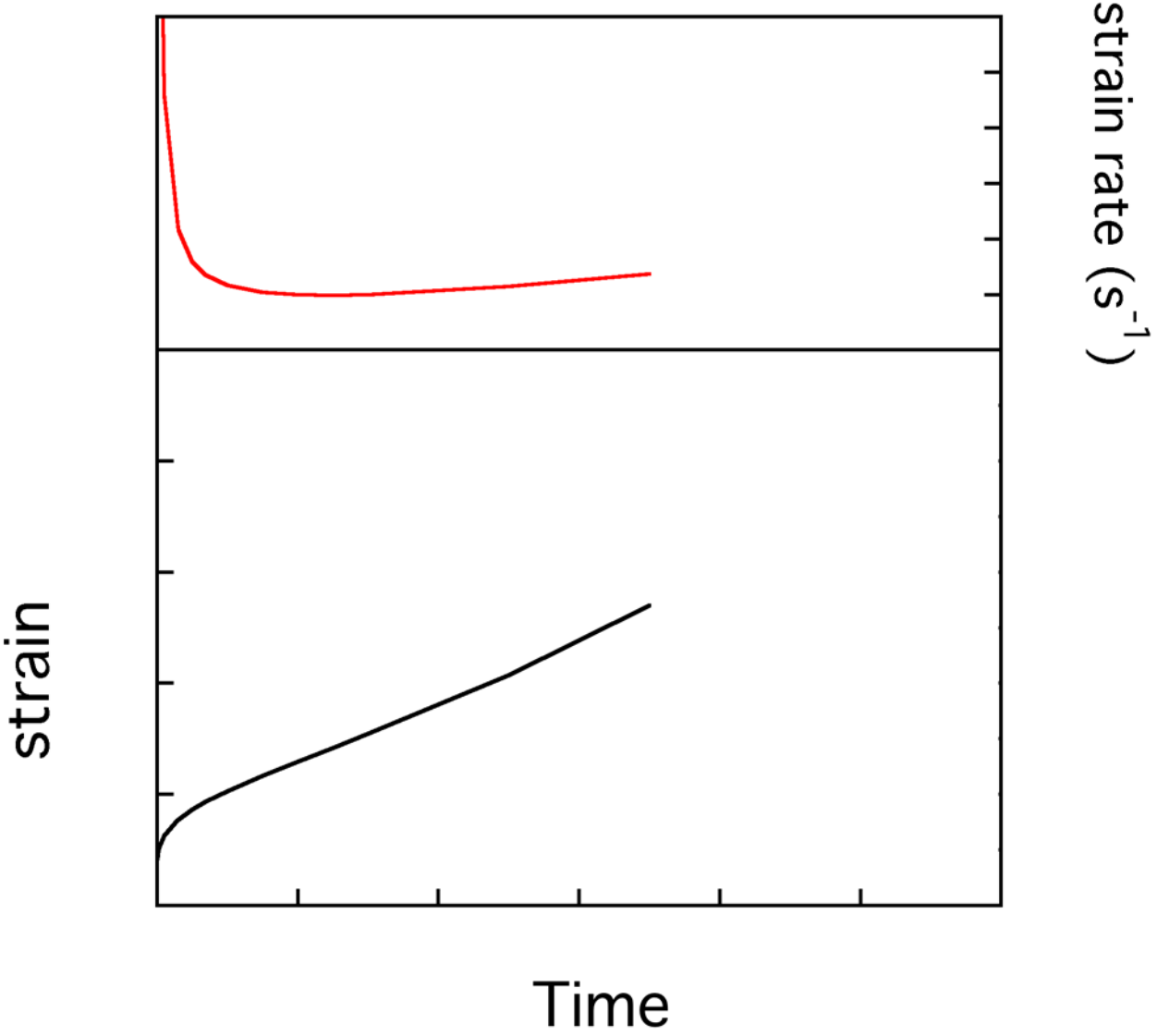

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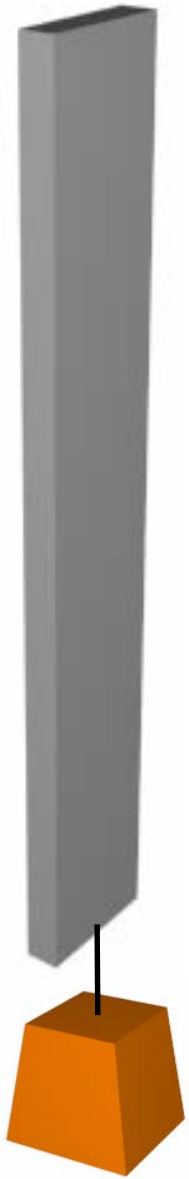

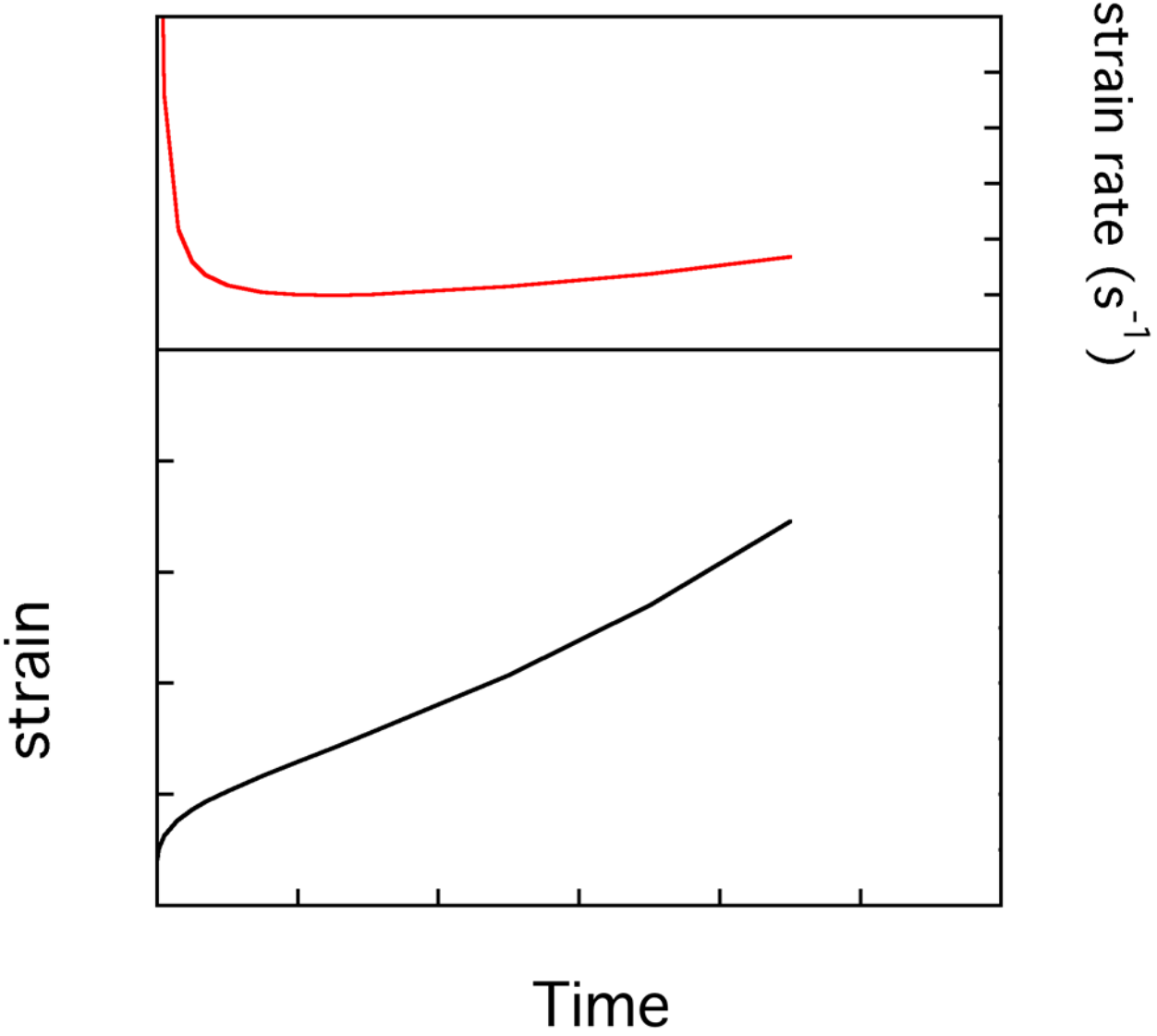

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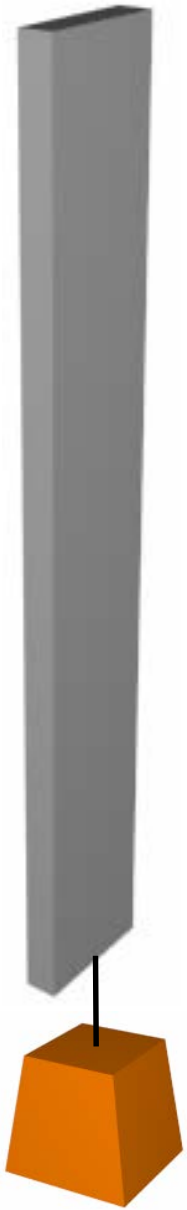

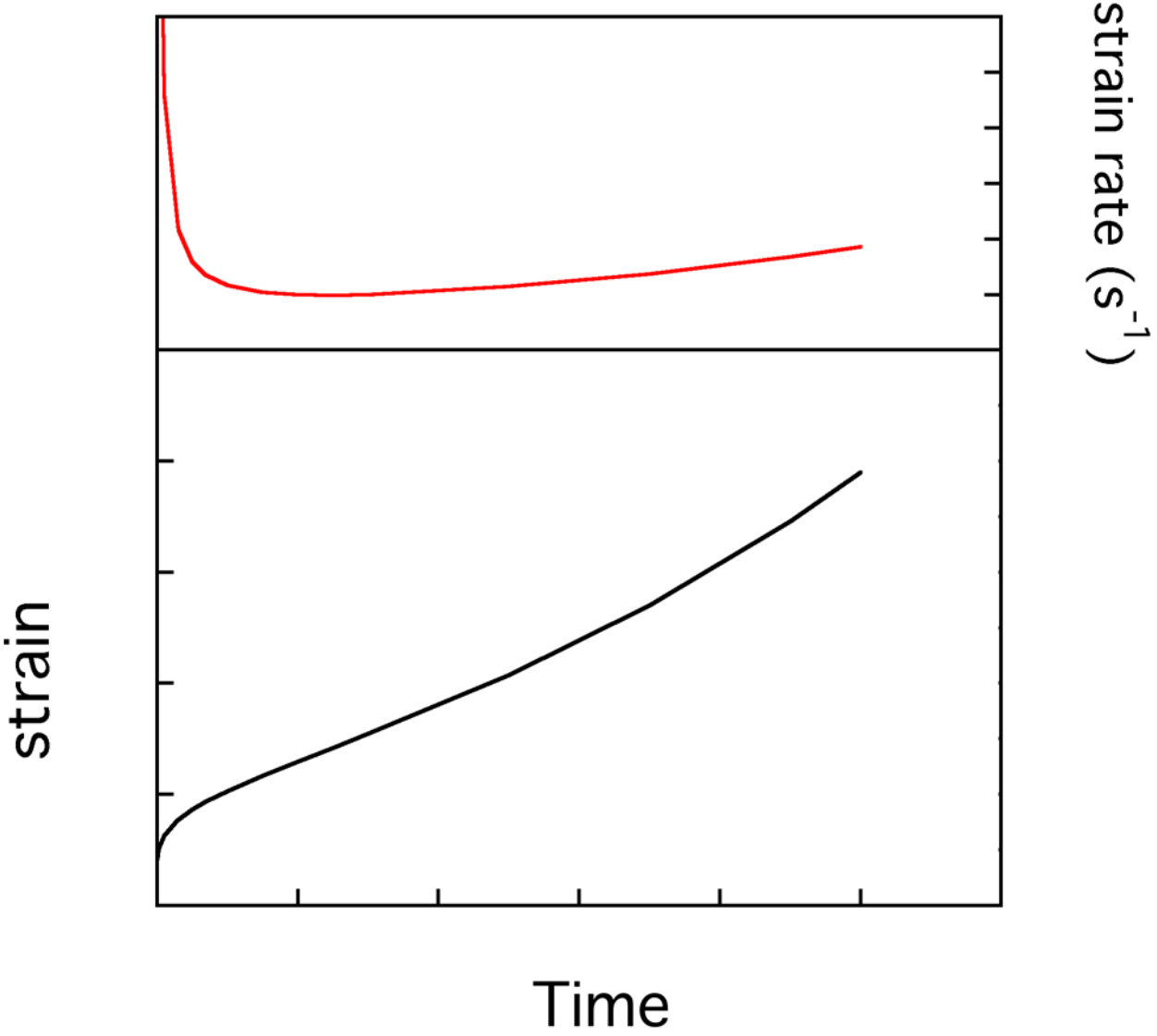

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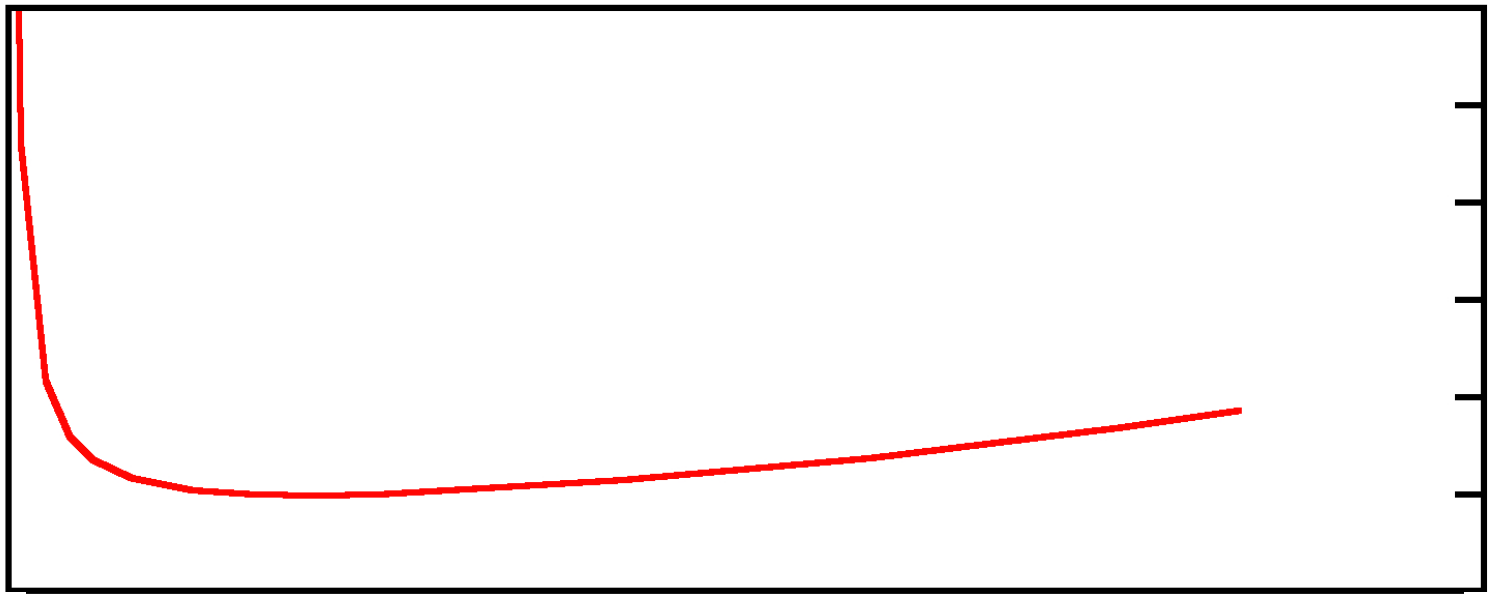

strain rate (s^{-1})

$$\frac{d\varepsilon}{dt} = A\,\sigma^{n}\,e^{-\frac{Q}{RT}}$$

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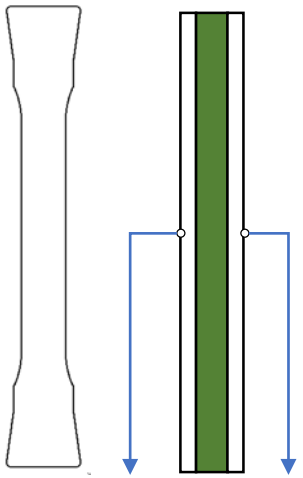
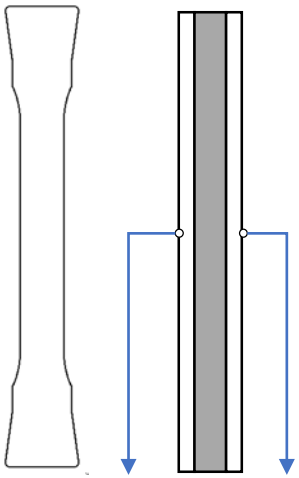
Methodology (Residual Stress Measurements by XRD)

As-processed



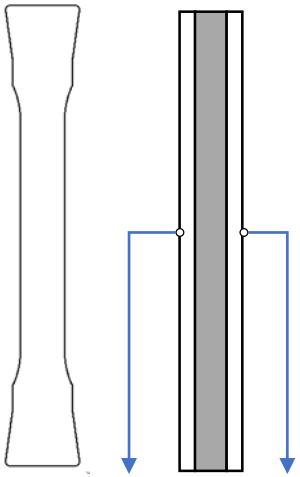
Residual Stress Measurement

After Reduction

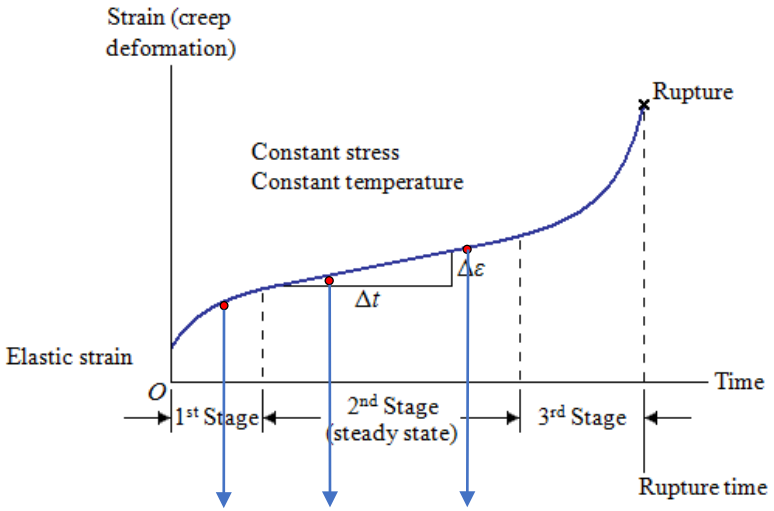


Residual Stress Measurement

After Creep Deformation
(by interrupting creep tests)



Residual Stress Measurement



Interrupted creep test

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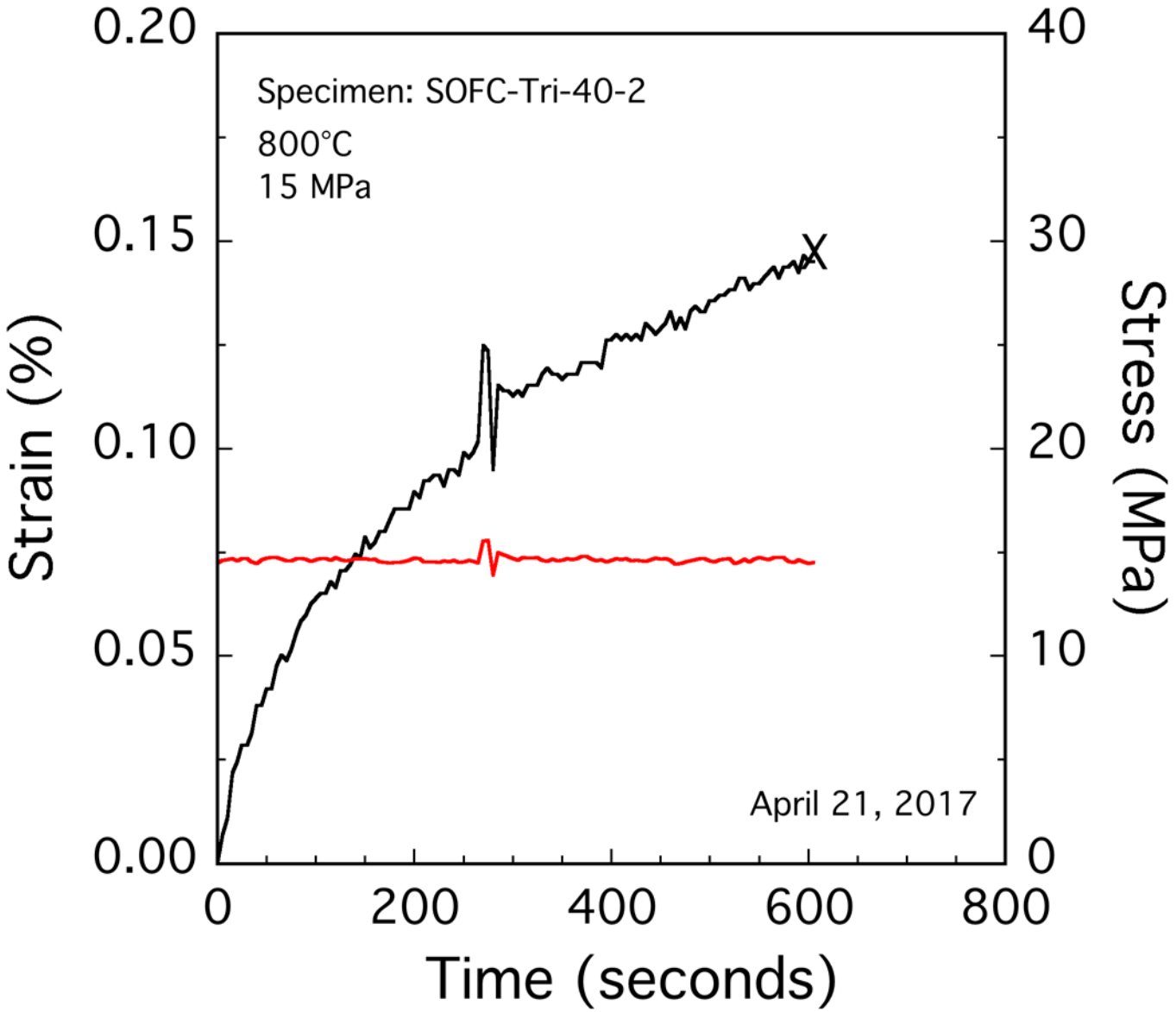
Creep Testing Results



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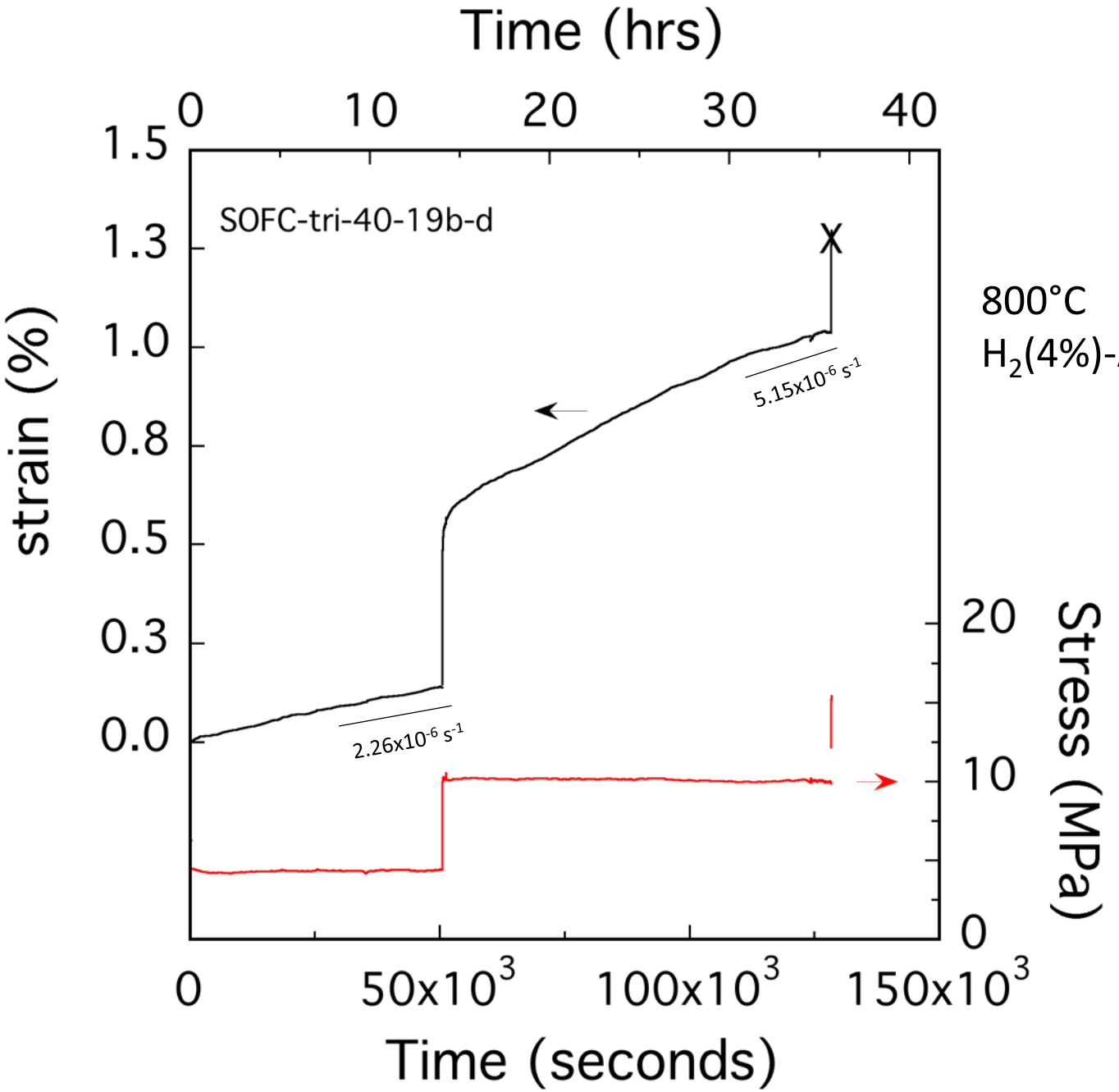
Creep Testing Results



800°C
H_2(4%)-Ar(96%)

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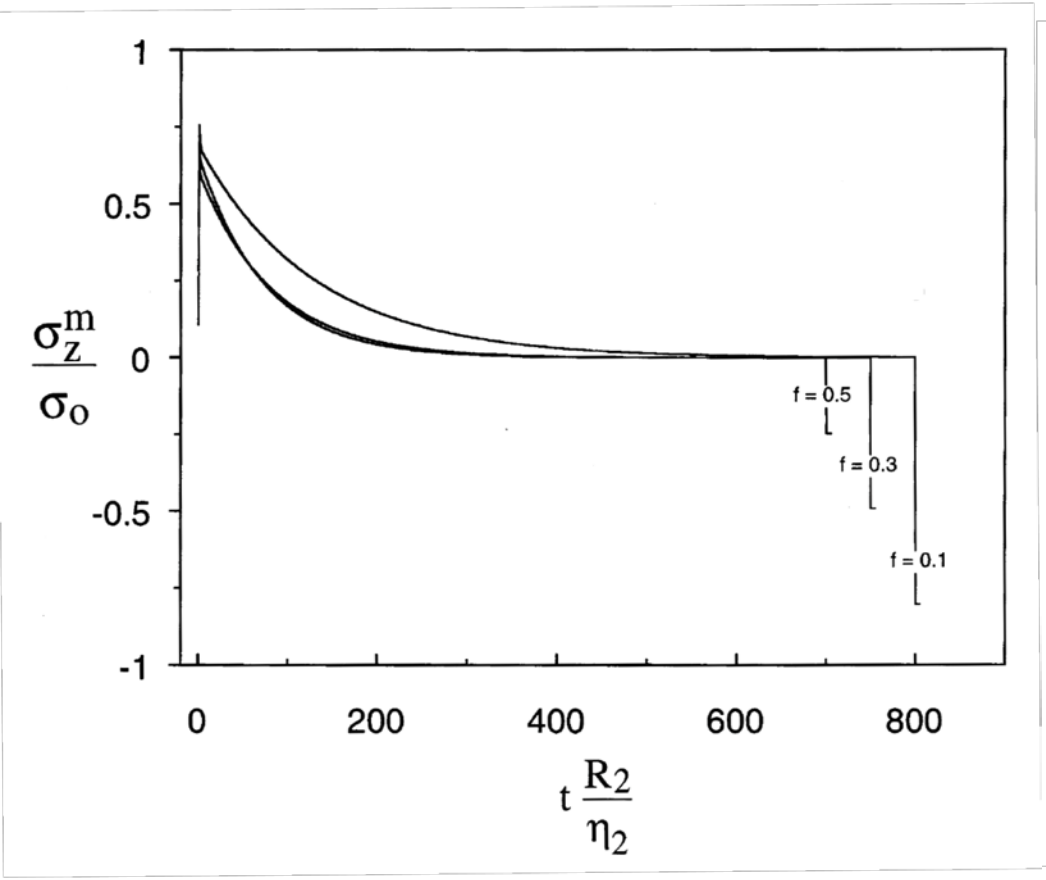
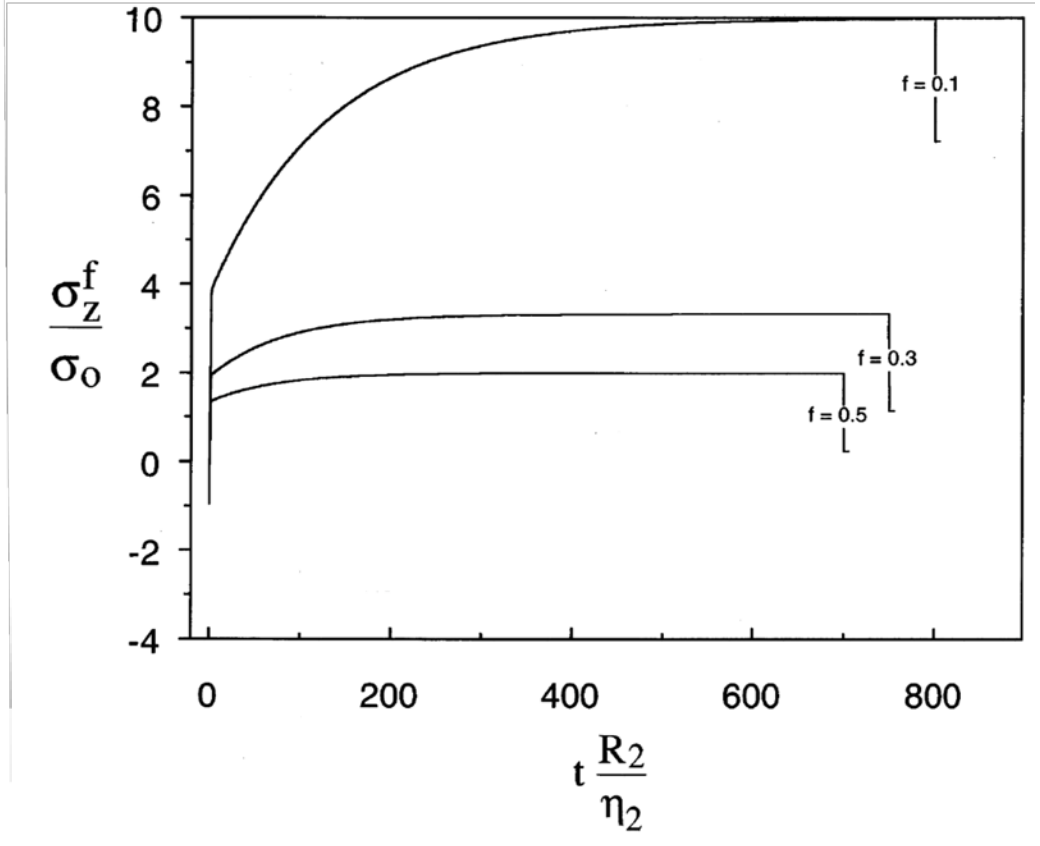
Stress Redistribution

Stress evolution in Ni-YSZ
(Sandwich Core)



Stress evolution in YSZ
(Sandwich Faces)

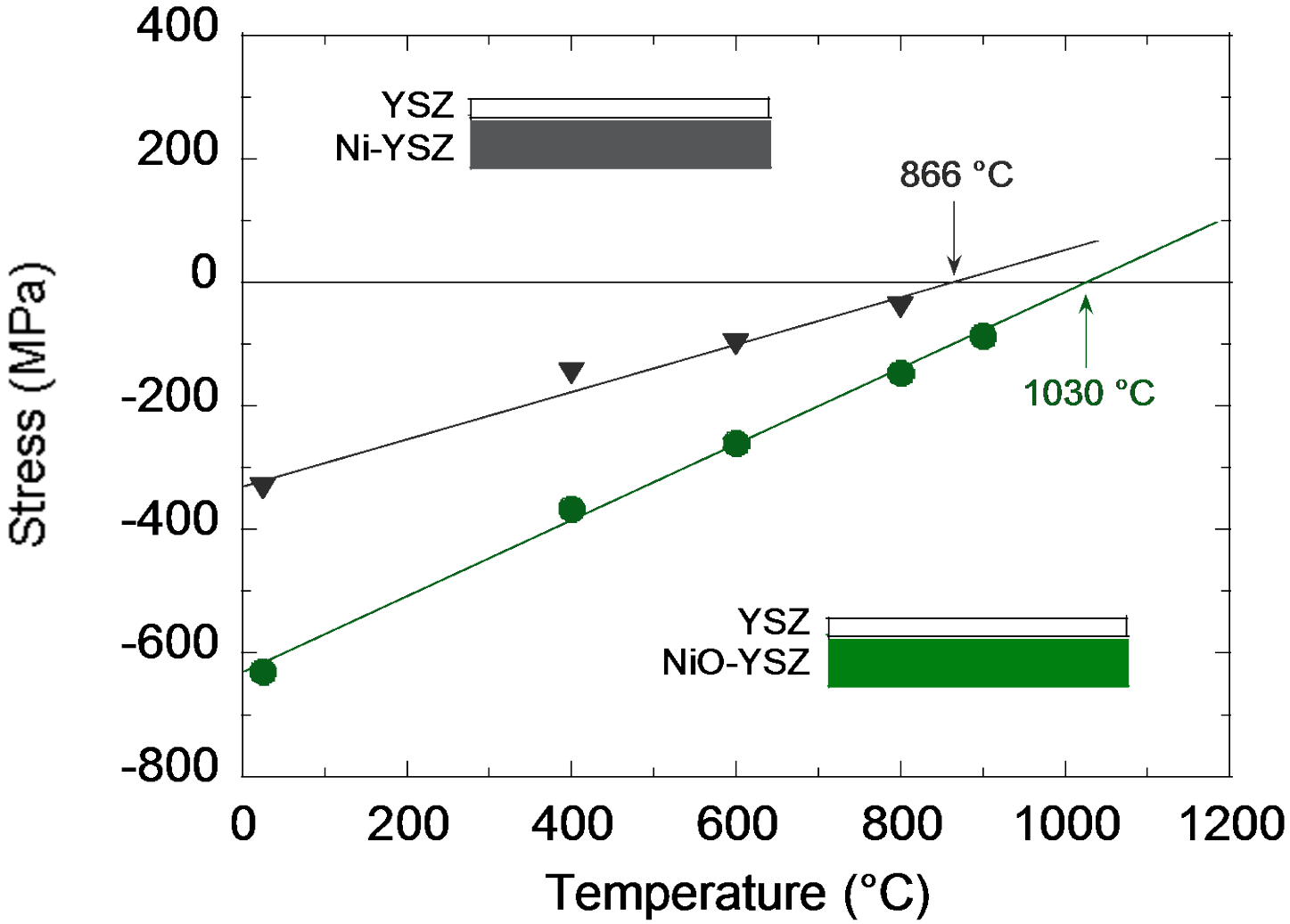


Summary

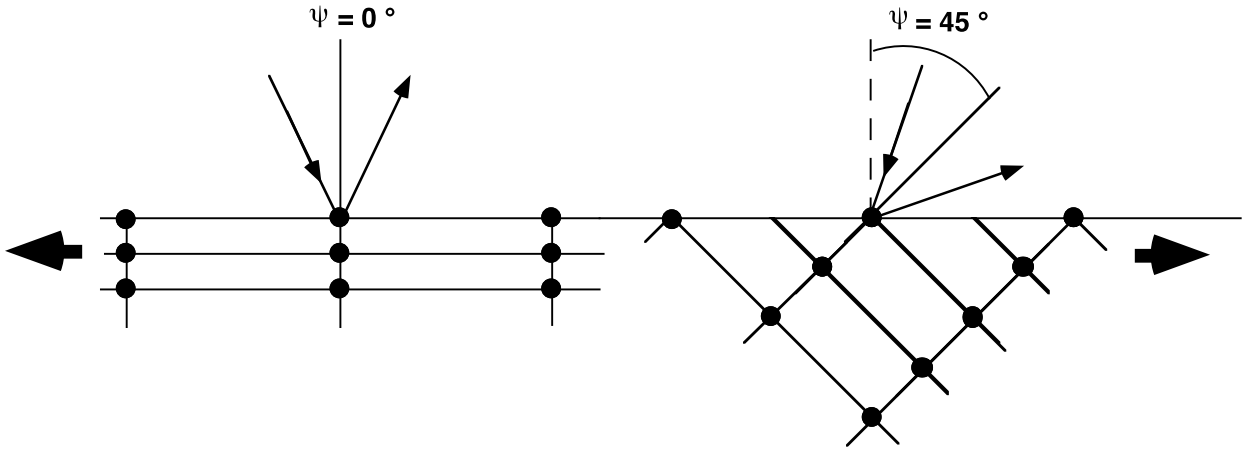
- The effect of creep deformation on the microstructure and functionality of anode materials is being investigated.
- The redistribution of stresses in SOFCs as a result of anode creep deformation is being investigated by measuring the evolution of residual stresses in the YSZ layers using a sandwich specimen configuration
- These results will be analyzed in the context of SOFC durability and reliability

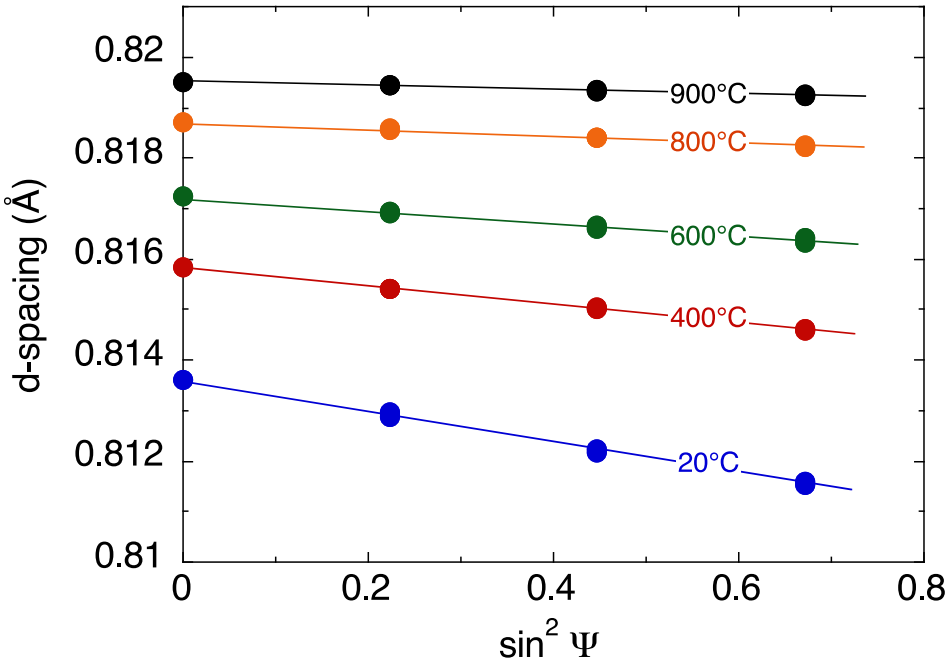
Residual and "Reduction" Stresses (X-ray diffraction)

800°C Reduction in 4%H_2-96%Ar



Residual Stresses in Ni-YSZ Sandwich Specimens





- Sample tilting is required for accurate strain measurement with x-rays
- Peak position as a function of tilt angle, ψ
- Slope of d (interplanar spacing) vs. $\sin^2\psi$ is used to calculate strain.