SAND2022-11862C

Tailoring the TRIP Effect in Q&P Steels using Strain Rate and Temperature

Christopher B. Finfrock[1,2*], Prof. Amy J. Clarke[2], Prof. Kester Clarke[2], and many others

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September 12-15, 2022

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Outline for Today

Introduction and research questions

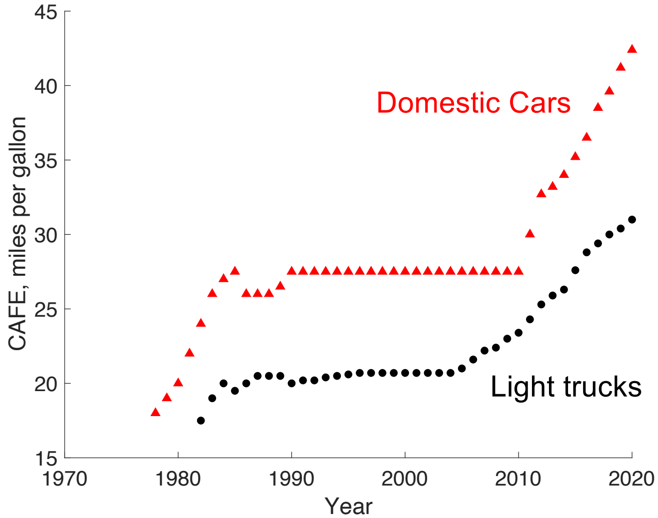
Selected results

Discussion and conclusions

Audience Q&A

Moving Targets for Automakers

Fuel Efficiency

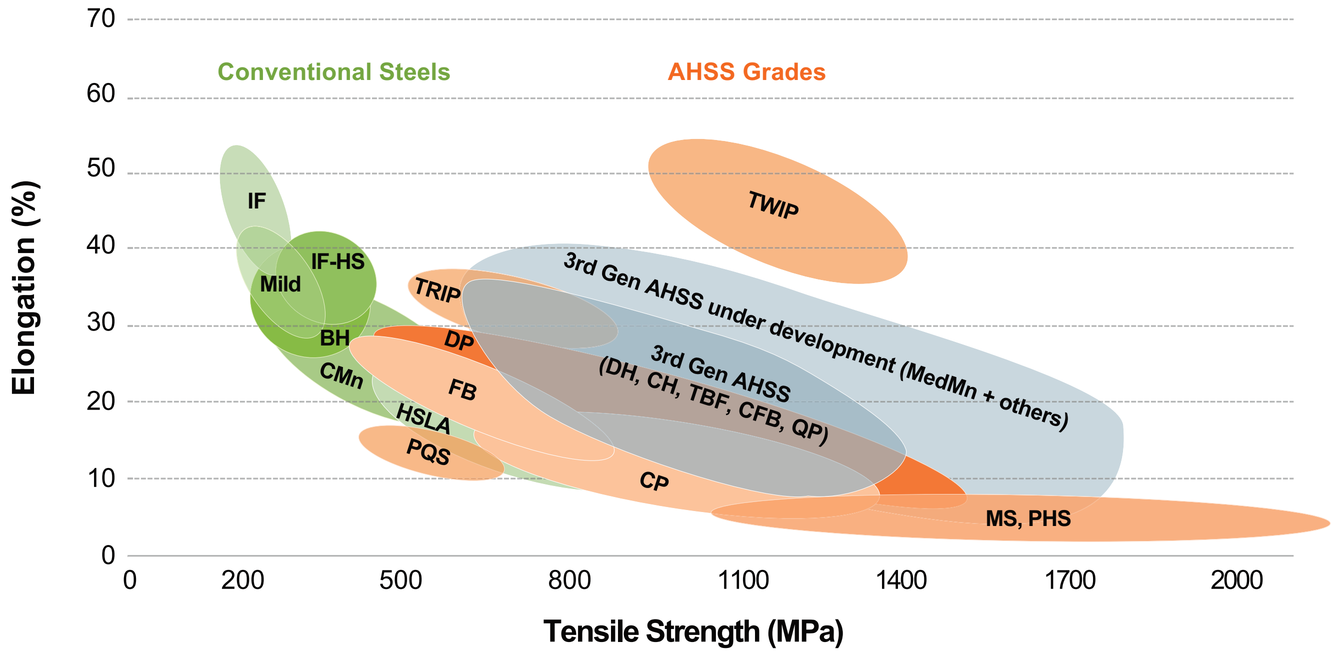


National Highway Traffic Safety Administration, "Summary of Fuel Economy Performance". 2022.

Crash Safety

Insurance Institute for Highway Safety, "About Our Tests". 2022.

AHSS are Under Development to Reach These Targets



Advanced high-strength steels (AHSS) have composite microstructures.

Third-generation AHSS rely on *retained austenite* for enhanced properties.

WorldAutoSteel, “A New Global Formability Diagram”, 2022.

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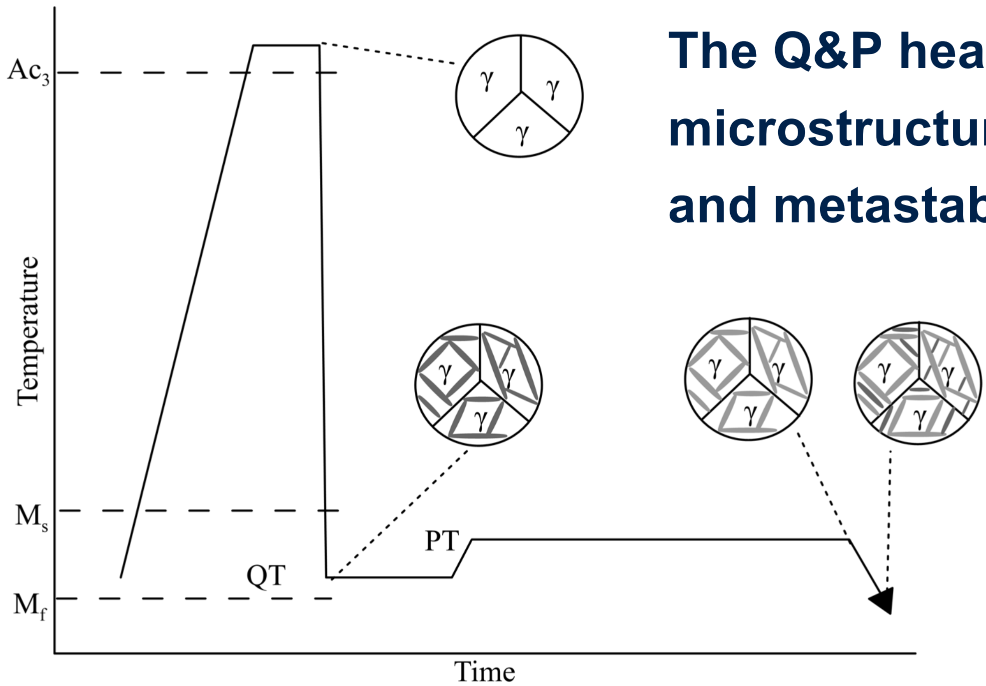
Quenching and Partitioning (Q&P)

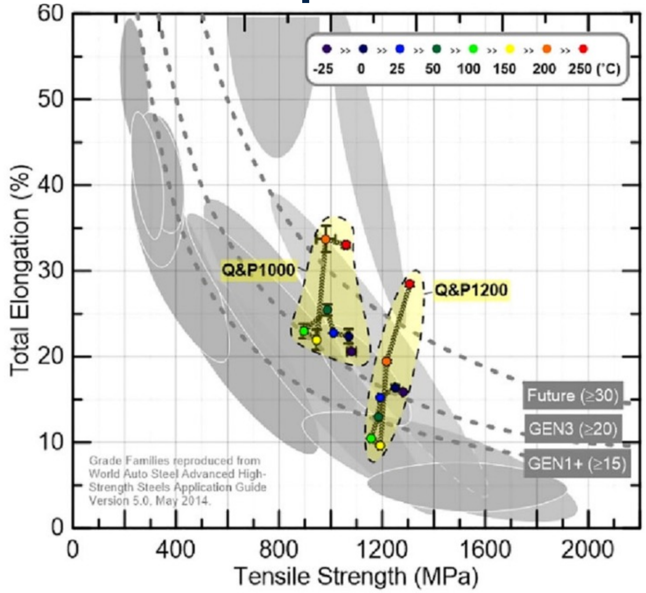


The Q&P heat treatment creates a complex microstructure containing ferrite, martensite, and metastable retained austenite.

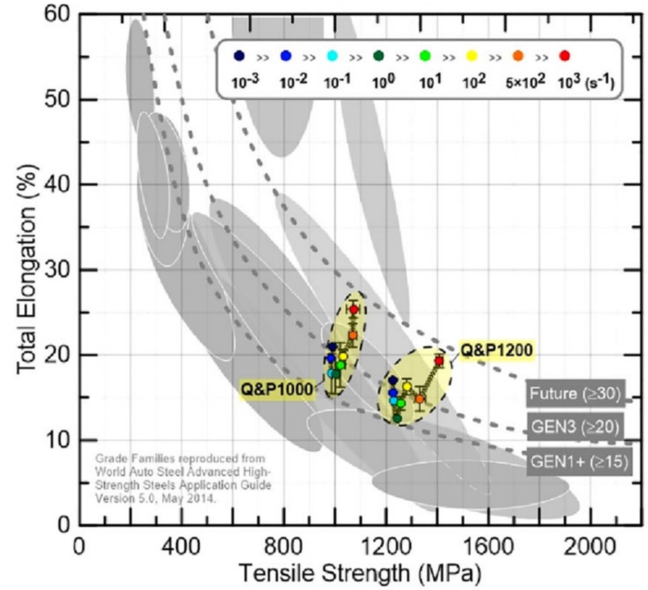
J.G. Speer, F.C.R. Assuncao, D.K. Matlock, D.V. Edmonds, "The 'Quenching and Partitioning' Process: Background and Recent Progress," Materials Research, vol. 8, no. 4, pp. 417-423, 2005. Figure replotted by M. Thrun.

Extrinsic Deformation Processing Factors

Temperature



Strain Rate

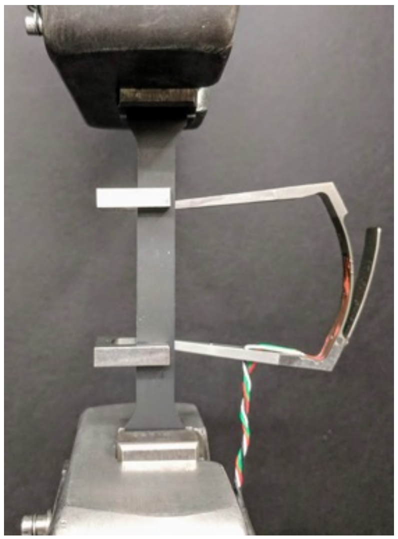


Deformation temperature and strain rate appear to control the properties.

How this relates to the martensitic transformation is not understood.

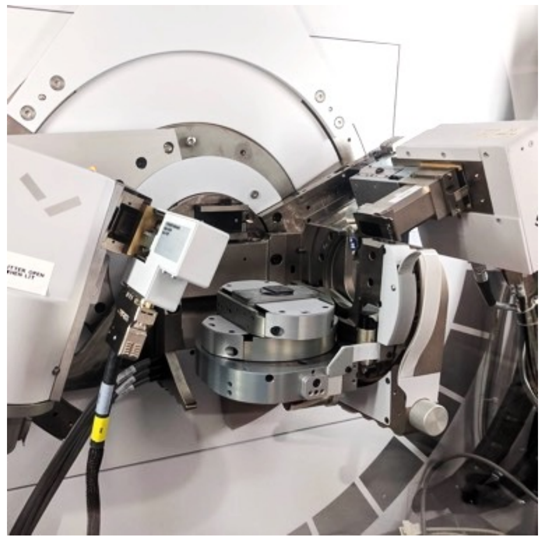
Framework for the Experimental Methods

Tensile Testing



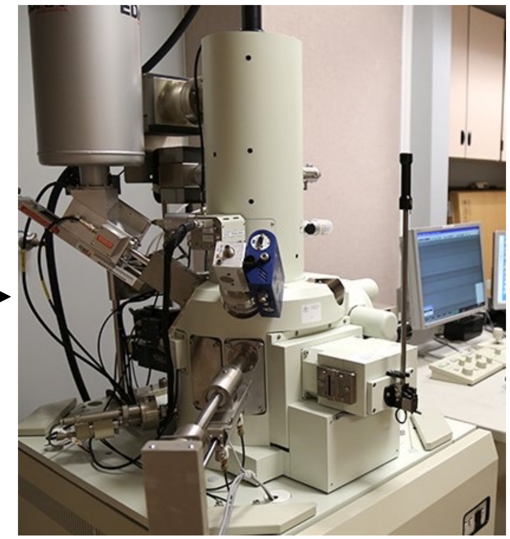
Mechanical behavior
of the bulk specimen
(mm-scale)

X-Ray Diffraction (XRD)



Crystallographic evolution of
the bulk specimen
(mm-scale)

Electron Backscatter Diffraction (EBSD)



Spatially-resolved
crystallographic information
(µm-scale)

Each experiment integrated mechanical testing, XRD, and SEM-EBSD

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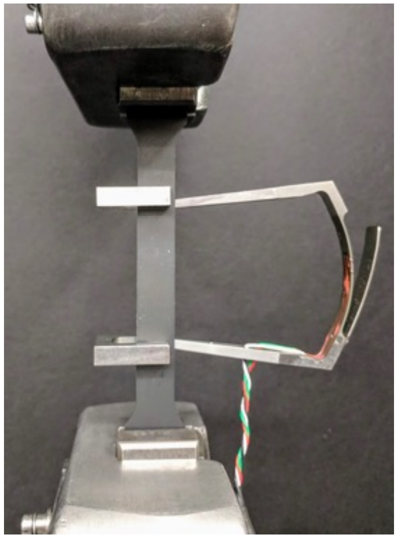

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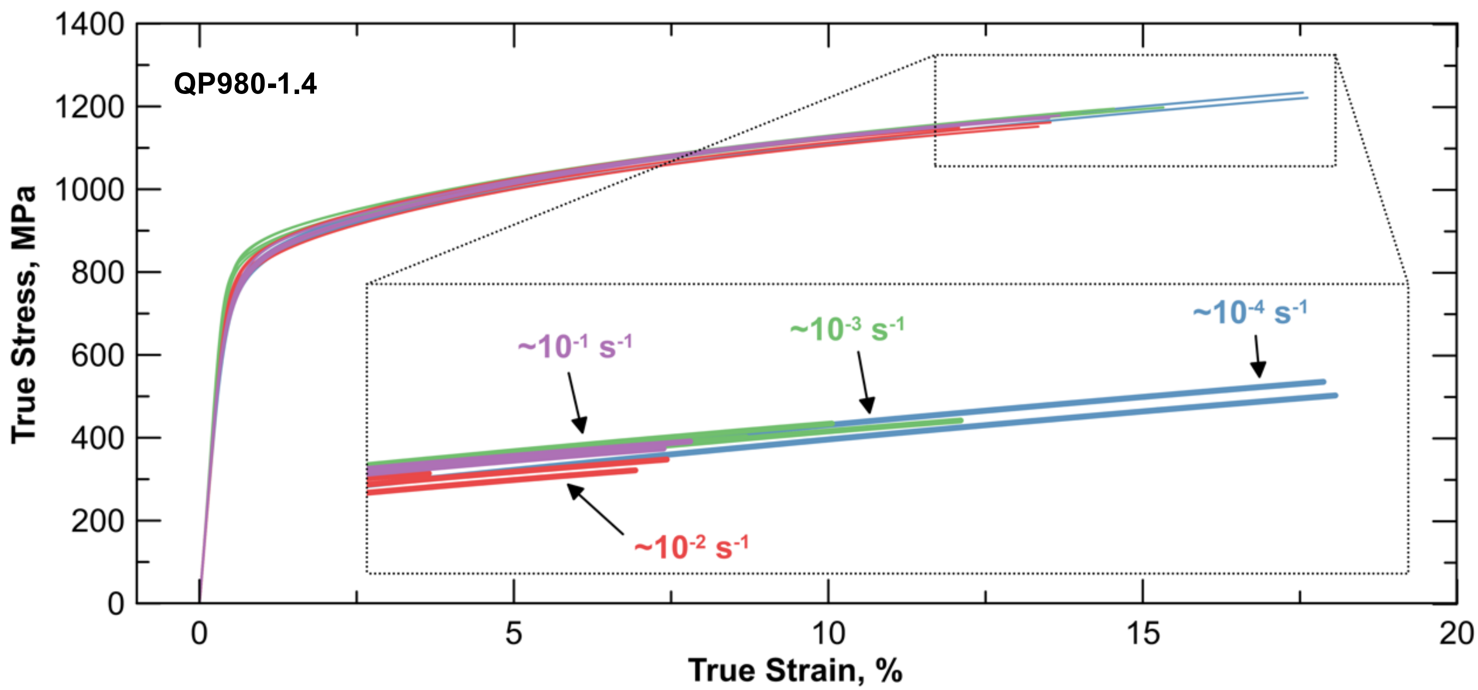
Results

1. How is DIMT responsive to strain rate?

Strain Rate Sensitivity of DIMT



C. B. Finfrock, M. M. Thrun, D. Bhattacharya, T. Ballard, A. J. Clarke, and K. D. Clarke, "Strain Rate Dependent Ductility and Strain Hardening in Q&P Steels," Metallurgical and Materials Transactions A, vol. 52A, pp. 928–942, 2021.

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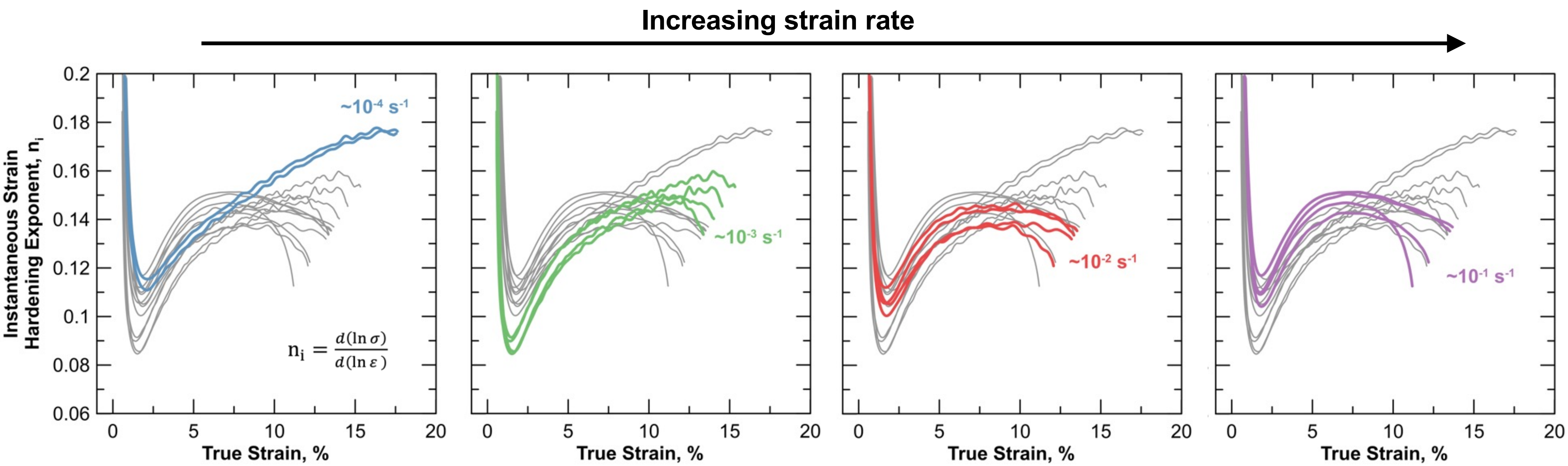

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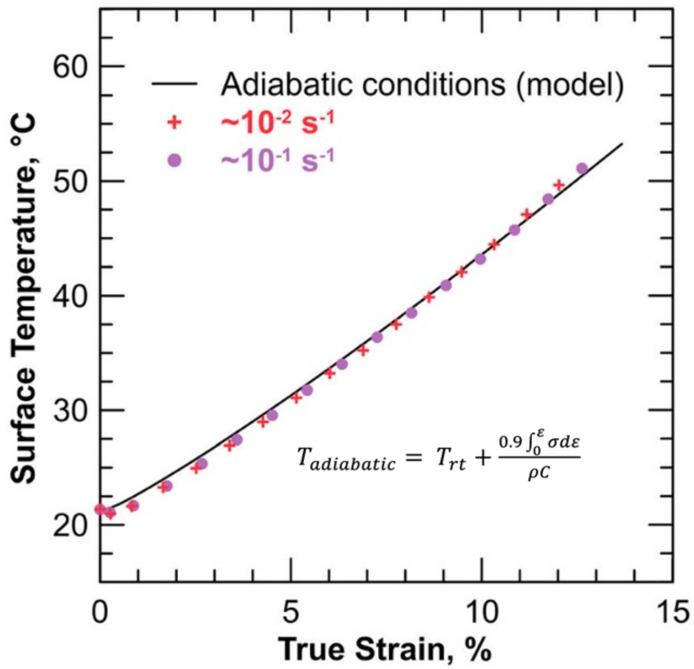

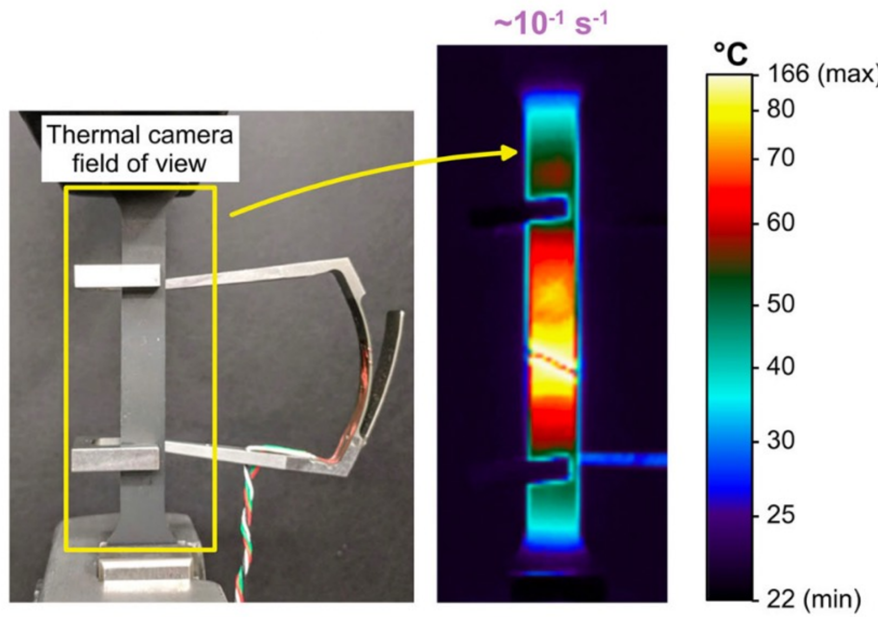

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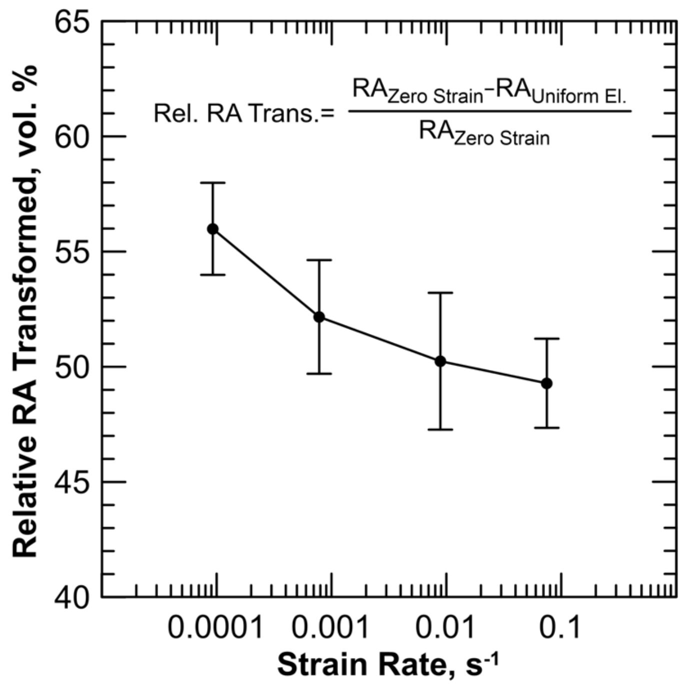

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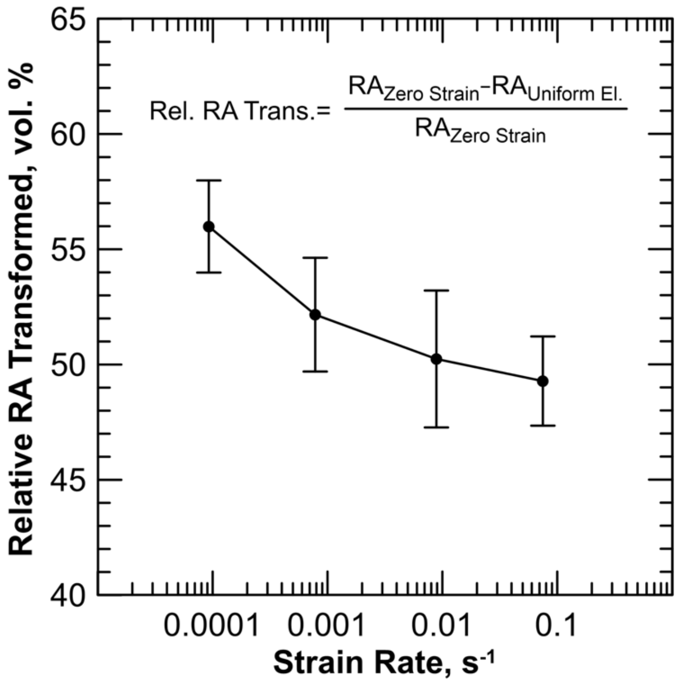


These data illuminate two challenges:

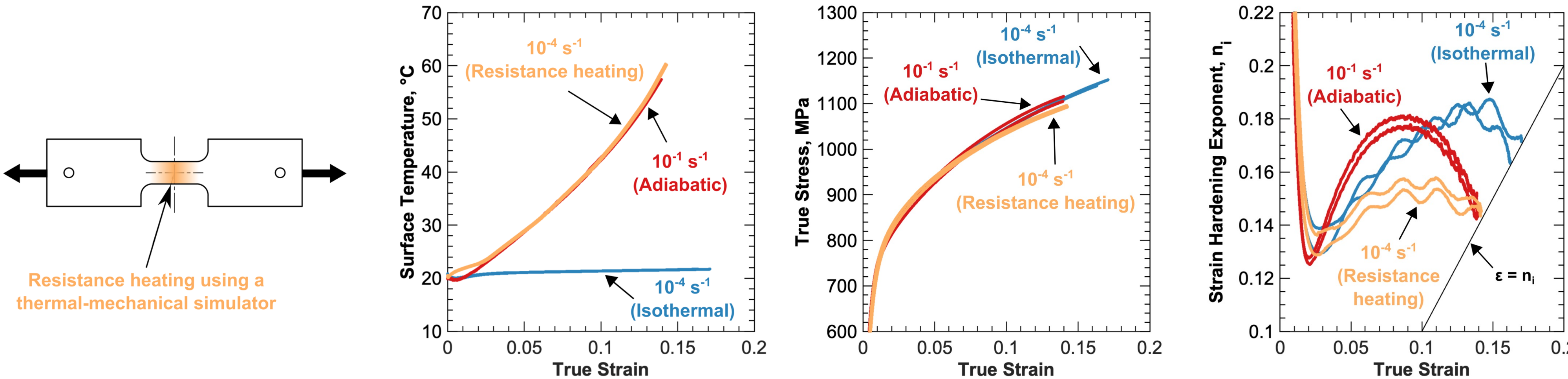
1. Strain rate and temperature are physically coupled. It is difficult to detect how each *individually* affect DIMT.
2. DIMT must be resolved as a function of strain or stress to understand the strengthening contribution of the TRIP-effect

C. B. Finfrock, M. M. Thrun, D. Bhattacharya, T. Ballard, A. J. Clarke, and K. D. Clarke, “Strain Rate Dependent Ductility and Strain Hardening in Q&P Steels,” Metallurgical and Materials Transactions A, vol. 52A, pp. 928–942, 2021.

Results

2. (a) Is the strain rate sensitivity of DIMT due to deformation-induced heating alone, or a combination of independent strain rate and temperature effects? (b) If there is a strain rate effect that is independent of temperature, then can this effect be measured at strain rates above the adiabatic threshold?

Decoupling Strain Rate and Temperature Effects on DIMT



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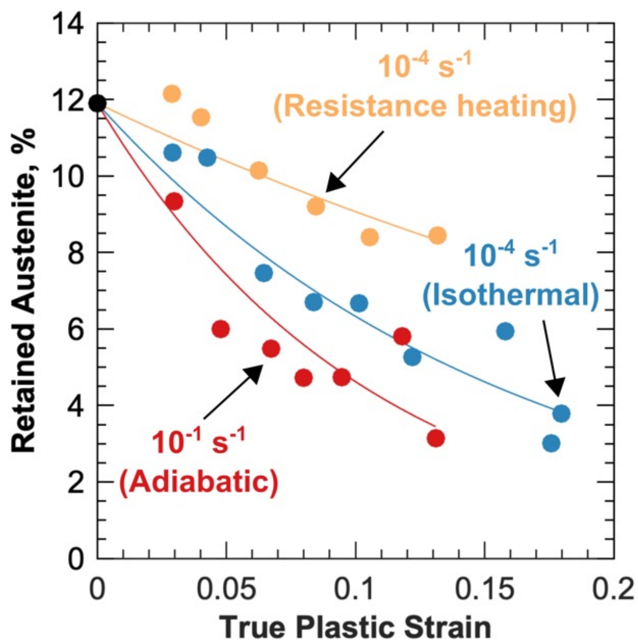

- Increasing the temperature *without* increasing the strain rate suppressed DIMT.
- Increasing the strain rate *without* changing the temperature enhanced DIMT.
- More rapid DIMT enhanced the strain hardening rate at a given tensile strain.

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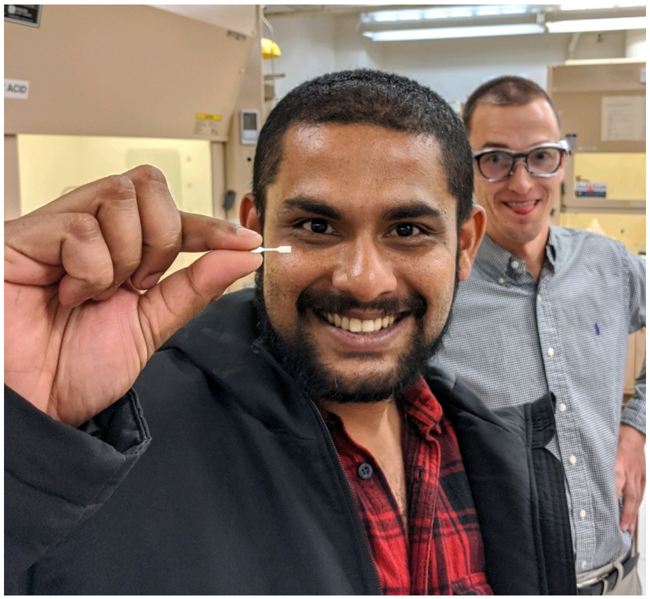
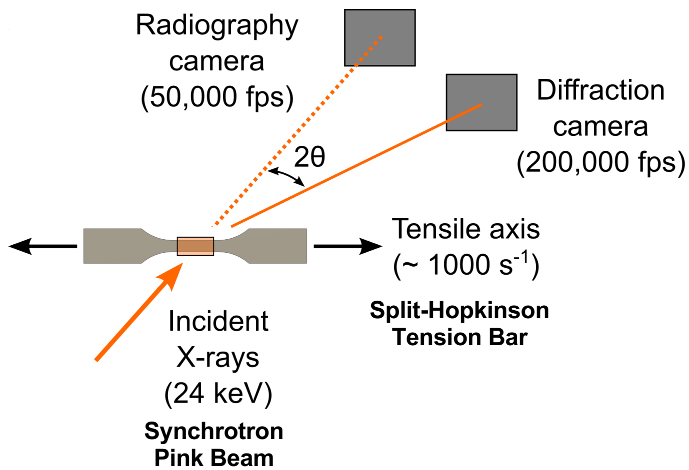
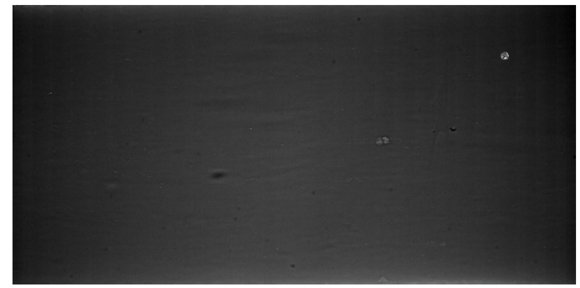
High Strain-Rate Pressure Bar Tests with Diffraction

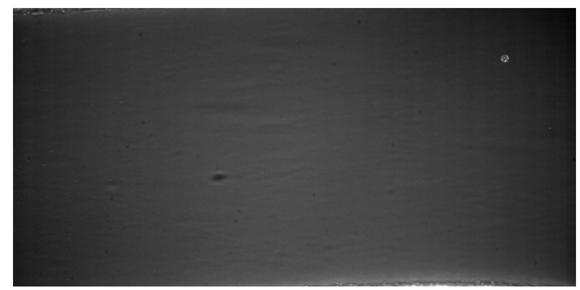




QP980-RD



QP1180-RD

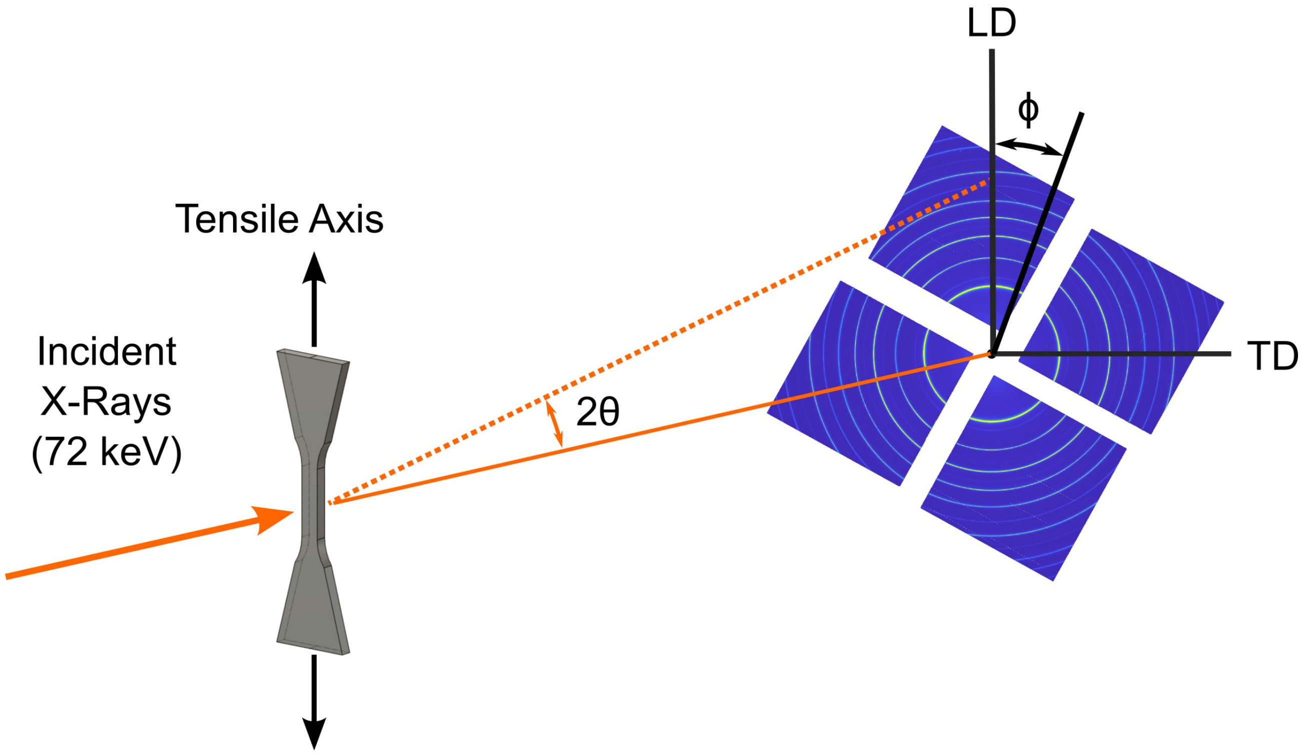


Finfrock et al., Resolving the Martensitic Transformation in Q&P Steels in-situ at Dynamic Strain Rates Using Synchrotron X-Ray Diffraction, MMTA, 2022.

Results

3. (a) Is DIMT sensitive to temperature over the range of 25 to 250 °C?
   (b) If so, is there an argument for using warm forming to tailor the martensitic phase transformation for improved performance during sheet forming and in service?

Resolving DIMT at Elevated Temperatures



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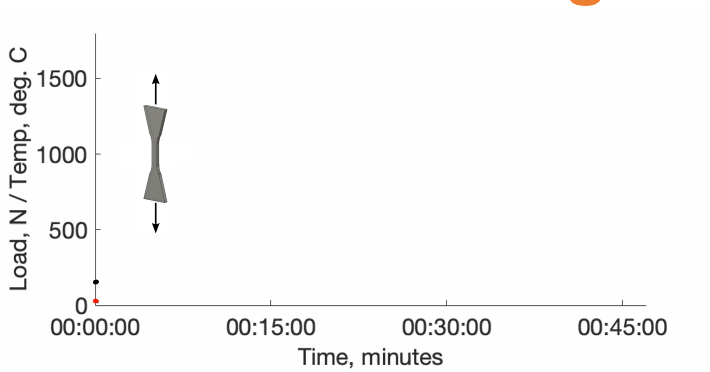

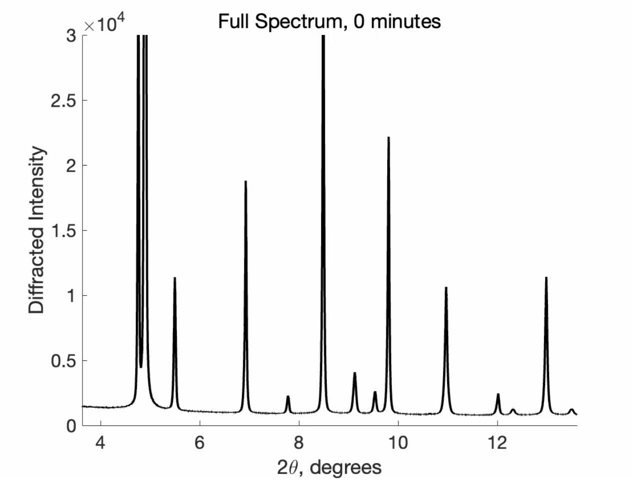

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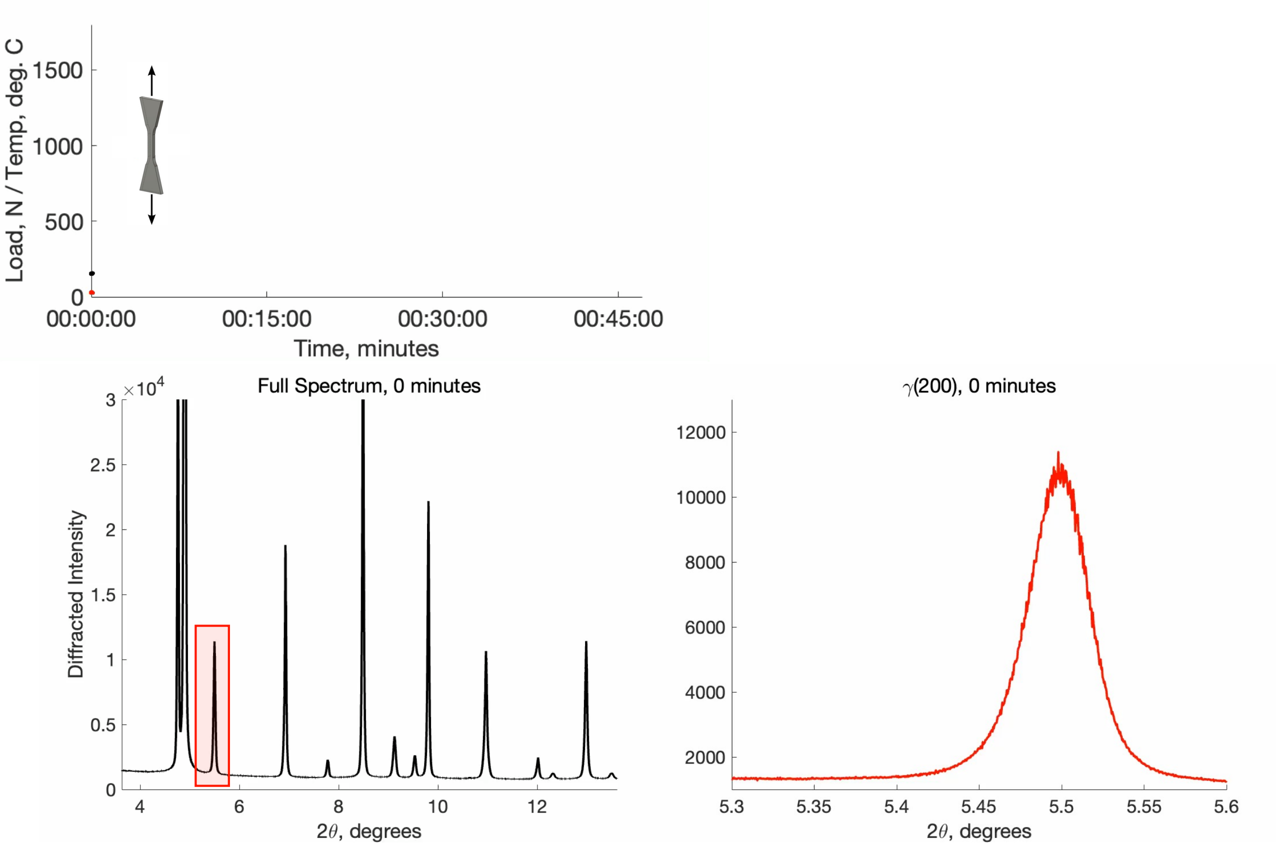

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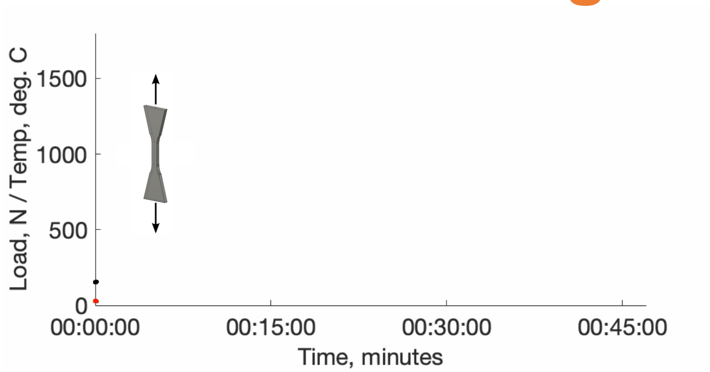
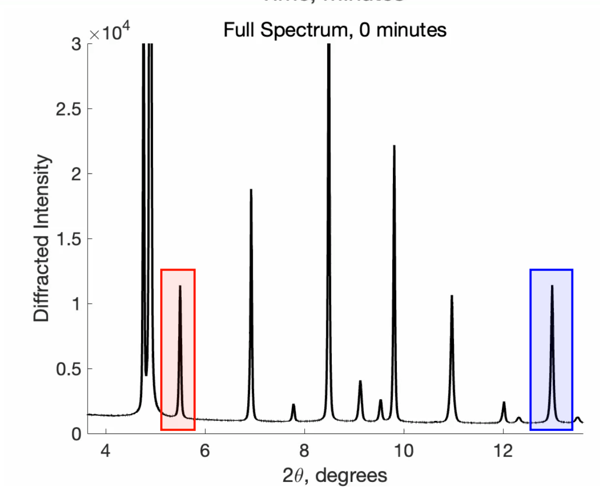
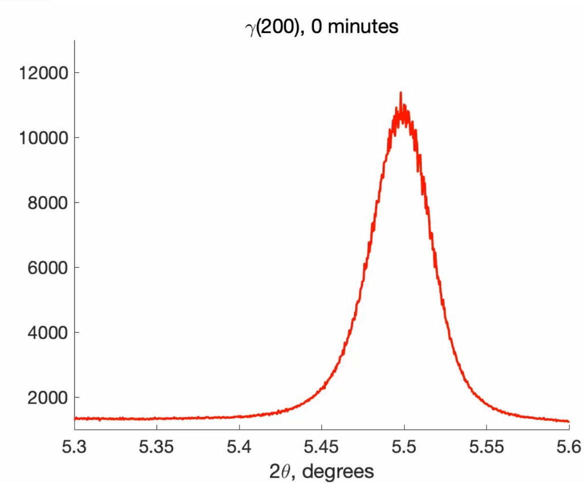
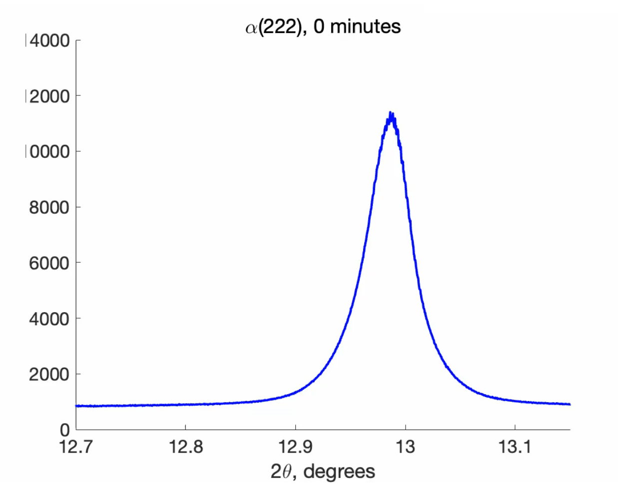


HEXRD provided *temporally-resolved* crystallographic information:

- Austenite fraction (V_γ)
- Plastic strain in ferrite/martensite (ε_α)
- Elastic stresses on each constituent (σ_γ and σ_α)







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Concluding Remarks

Adiabatic heating in Q&P steels was quantified
MS&T 19

Anisotropy was linked to austenite stability
MMTA 2020

DIMT was strain rate sensitive
MMTA 2021

Strain rate and temp were decoupled
JOM 2022

DIMT was resolved at dynamic rates
MMTA 2022

DIMT was resolved at elevated temperatures
Acta Mat 2022

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