Project 33B-L: In-Situ Studies of Strain Rate Effects on Phase Transformation and Microstructural Evolution in Multi-Principal Element Alloys

Fall 2018 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 2-4, 2018

Student: John Copley (Mines)
Faculty: Amy Clarke (Mines)
Industrial Mentor: TBD
Other Participant: Francisco Coury (UFSCAR)

Project 33B-L: In-Situ Studies of Strain Rate Effects on Phase Transformation and Microstructural Evolution in Multi-Principal Element Alloys

CANFSA
Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

- Student: John Copley (Mines)
- Advisor(s): Amy Clarke (Mines)

Project Duration
MS: September 2018 to May 2020

- Problem: The effects of strain rate and state and temperature on the TRIP/TWIP behavior exhibited by MPEAs are not well understood.
- Objective: Determine the relationship between temperature, strain rate and strain state effects on the evolution of deformation twins and deformation induced phase changes.
- Benefit: Improved understanding of TRIP/TWIP behavior seen in other materials, alloy design for specific applications, especially blast resistance.

Recent Progress

- Initial microstructural characterization of a selected multi-principal element alloy (MPEA) indicates TRIP/TWIP behavior.
- In-situ diffraction measurements during thermomechanical processing (Gleeble) in Brazil have been performed by Dr. Francisco Coury.

Metrics

Description	% Complete	Status
1. Literature review	20%	●
2. Quasi-Static Testing	10%	●
3. Microstructural Characterization	2%	●
4. Dynamic Testing	0%	●
5. Multi-scale in-situ imaging and diffraction	0%	

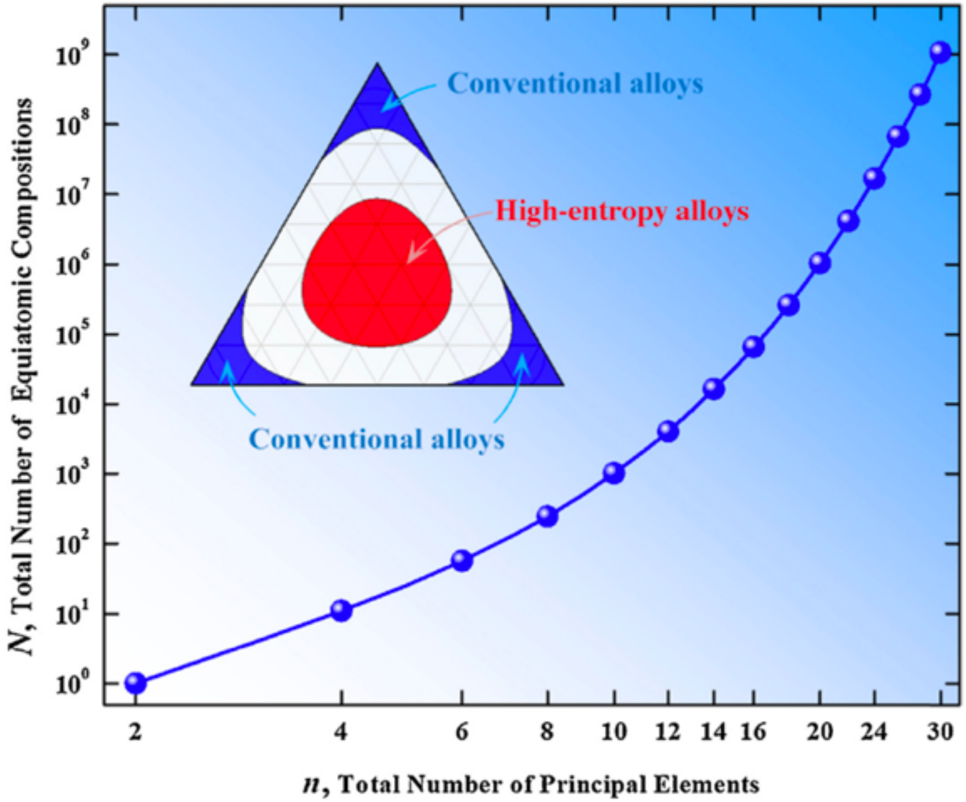
Industrial Relevance

- Understanding of TRIP/TWIP of MPEAs during high rate deformation
  - New strategies to design deformation mechanisms
  - Drive development of alloys for blast-resistance and performance in extreme environments

- Fundamental understanding of TRIP/TWIP
  - Applications to more commonly used Advanced High Strength Steels

MPEAs

- No definable main element
  - Equiatomic, or
  - Several (>2) components present in very high concentrations
- Almost infinite combinations
- Commonly referred to as High Entropy Alloys (HEAs) and/or Complex Concentrated Alloys (CCAs)



Y.F. Ye, Q. Wang, J. Lu, C.T. Liu, Y.Yang. Materials Today, 2016, 19(6):349-362

Project Background: MPEAs

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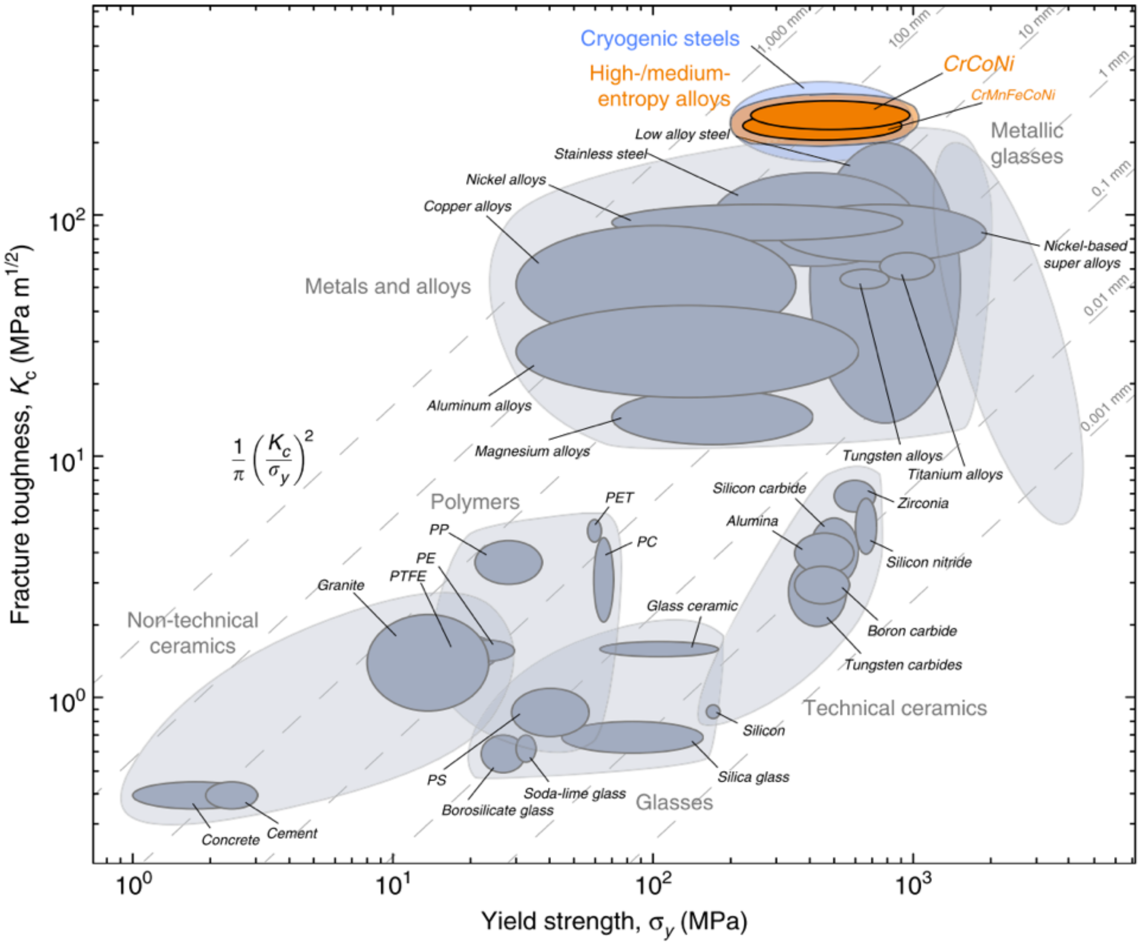
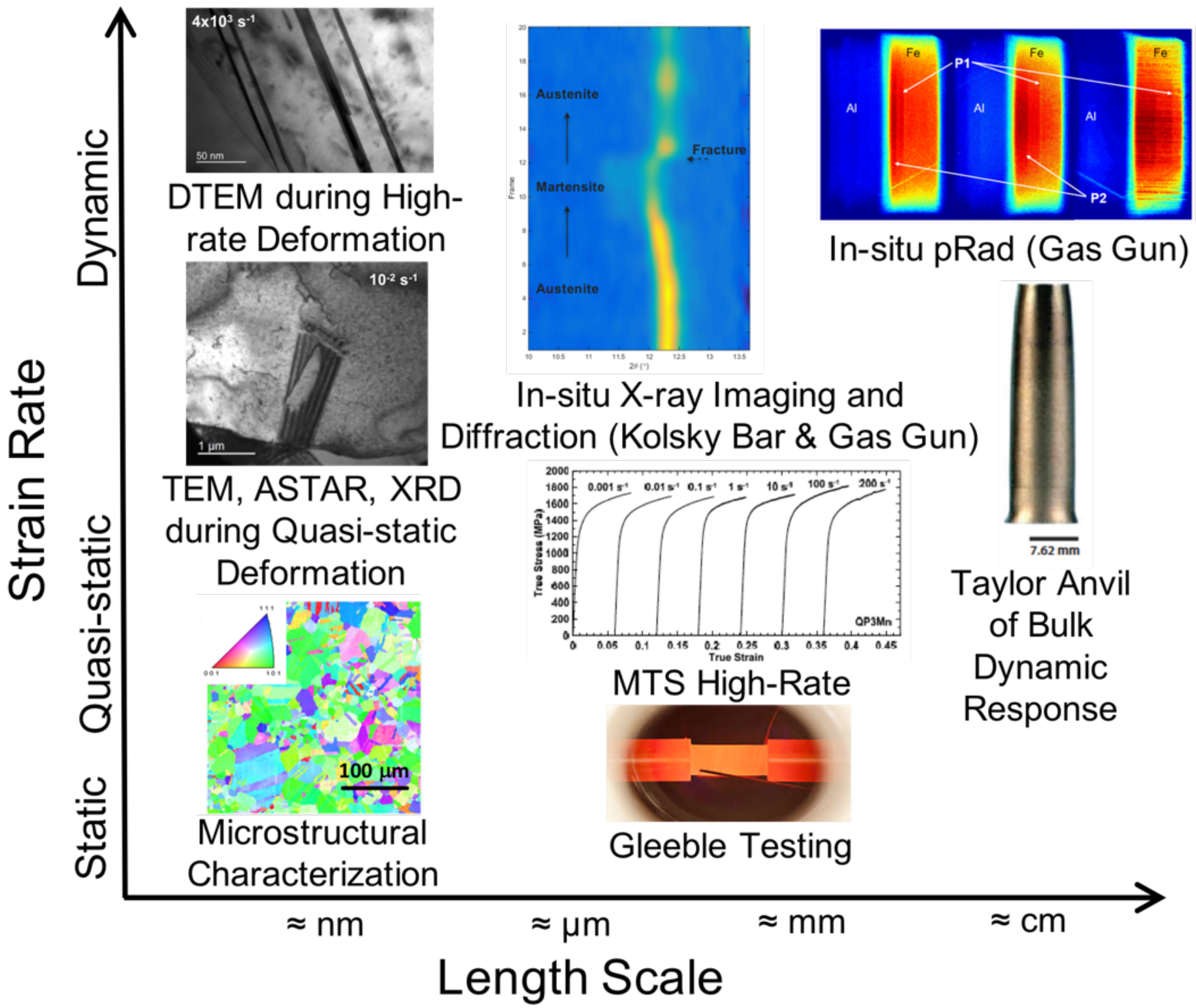


B. Gludovatz, et al., Nature Communications, 2016, 7:10602

- High Entropy Alloy
  - Restrictive definition
    - $S_{config} \geq 1.5R$
  - Entropy does not correlate to properties
- Multi-Principal Element
  - Broader definition
  - CoCrNi Family
    - Toughest known CCAs
    - Fails HEA criteria

Project Vision

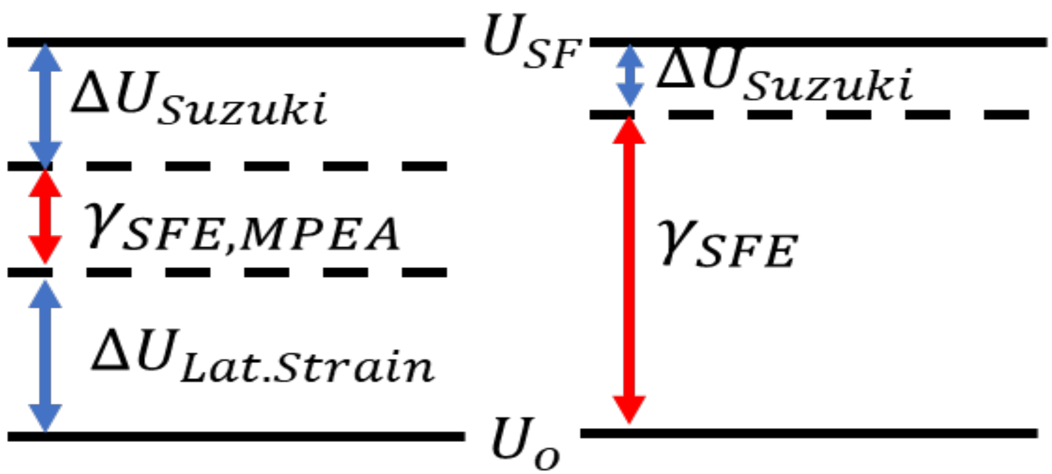


State-of-the-art, multi-scale microstructural characterization with electrons, x-rays, and protons of TRIP/TWIP in MPEAs for blast resistance

Figure courtesy of Dr. Amy Clarke

Project Background: Reasons for TRIP/TWIP

- Deformation accommodated by change in local atomic stacking
- Shown to occur in some MPEAs
  - CoCrNi, FeCoCrNi, FeMnCoCr, FeMnCoCrNi
- High occurrence of twins is expected (low SFE)
  - Suzuki Interaction
  - Lattice Distortion



Project Background: Effects of TWIP/TRIP

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- Increased work hardening rates
  - Burgers vectors are not conserved at twin interfaces
  - High work hardening rates delay instability
- Delayed Instability
  - Increased UTS, elongation
  - Improved toughness

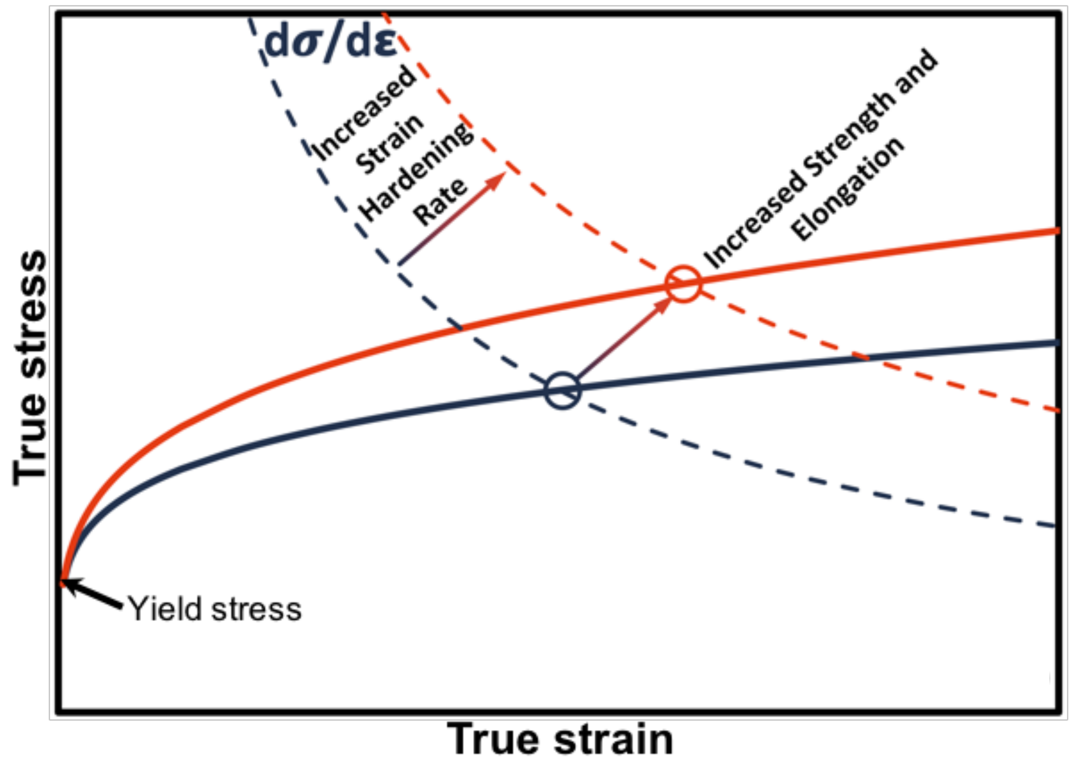
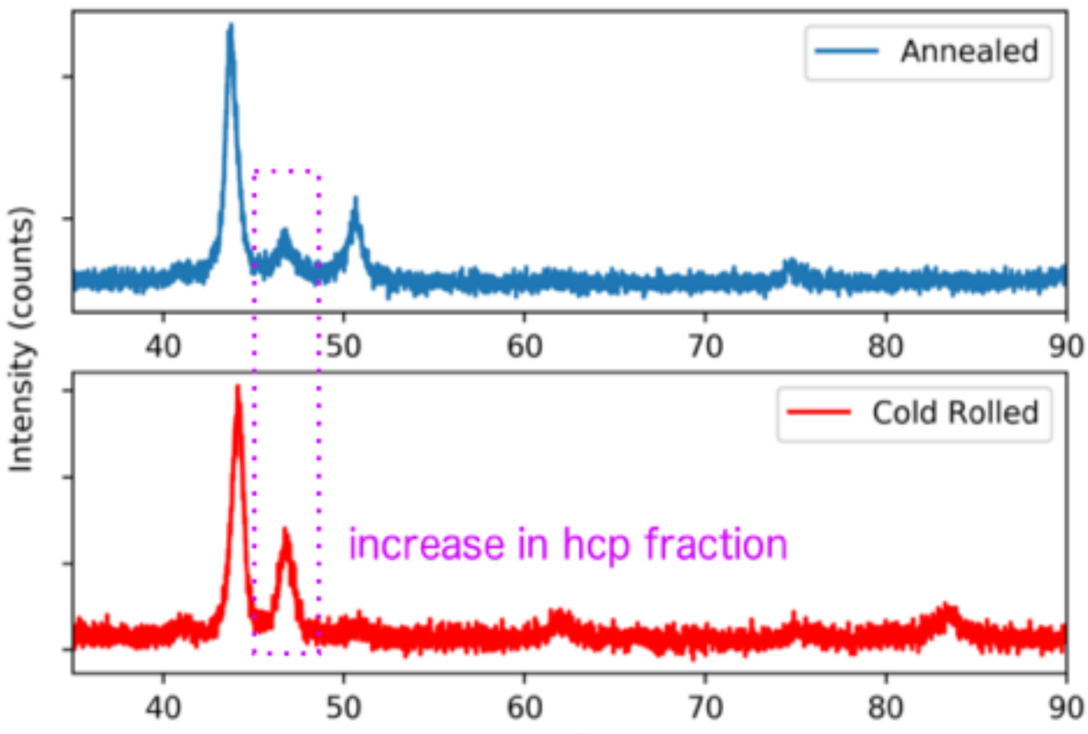
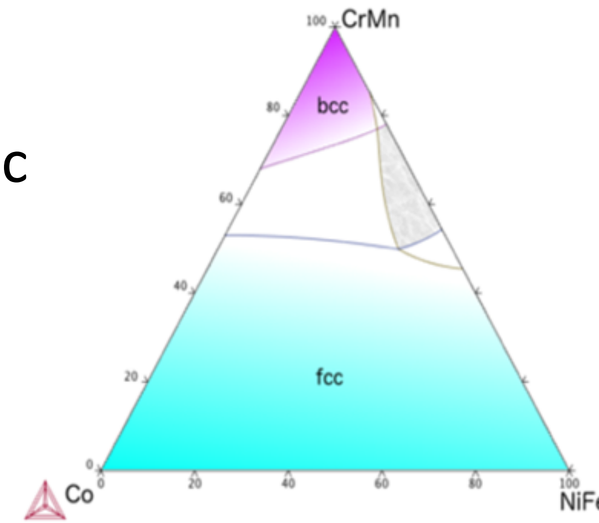


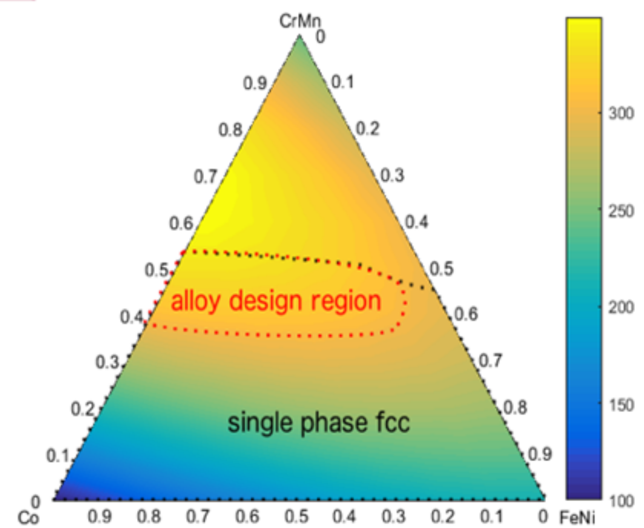
Figure courtesy of Dr. Kester Clarke

Recent Progress

- Initial alloy design space identified
- Evidence of TRIP/TWIP in non-equiatomic MPEA derived from FeMnCoCrNi HEA
  - Increase in HCP following cold rolling



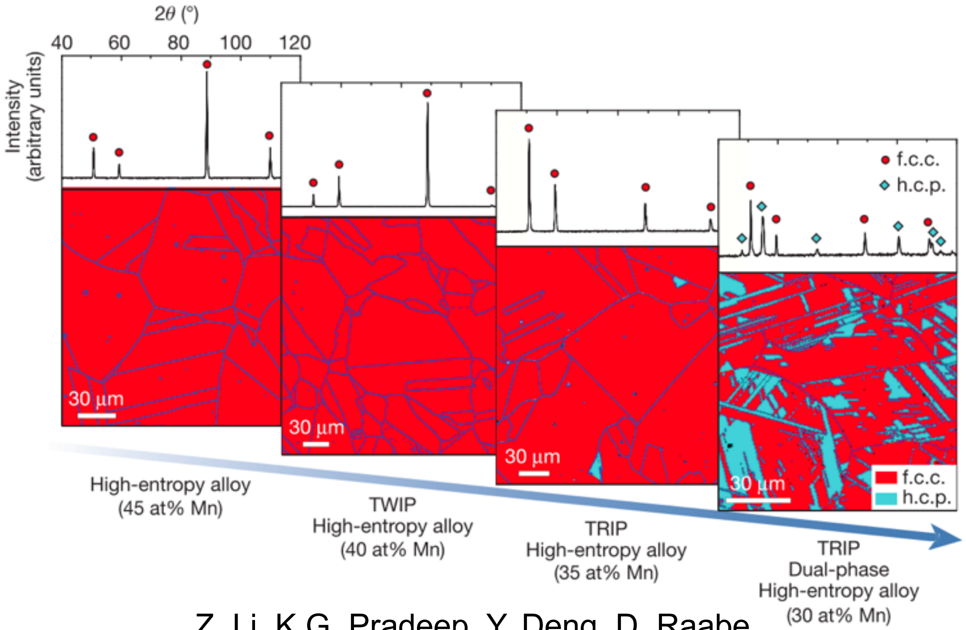




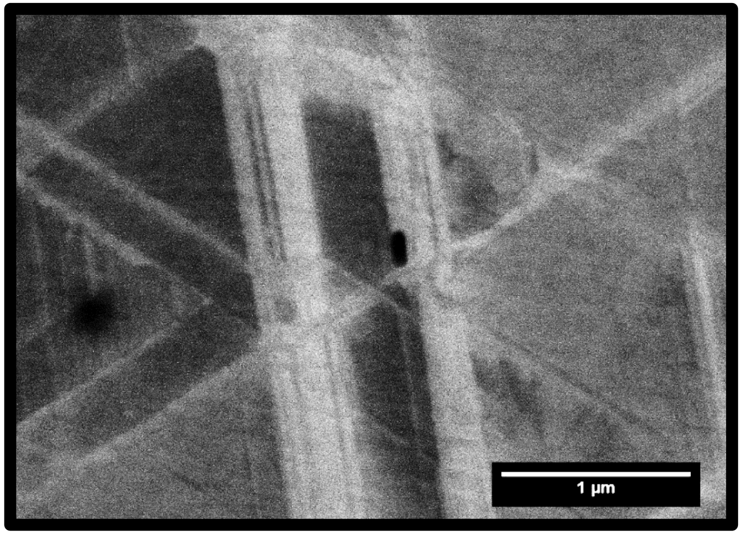
Figures courtesy of Dr. Francisco Coury

Future Work

- Investigation of multi-phase MPEAs with desirable properties
- High-throughput thermodynamic modeling to identify non-equiatomic MPEAs that will TRIP/TWIP



Z. Li, K.G. Pradeep, Y. Deng, D. Raabe, C.C. Tasan. Nature 2016, 534:227-230

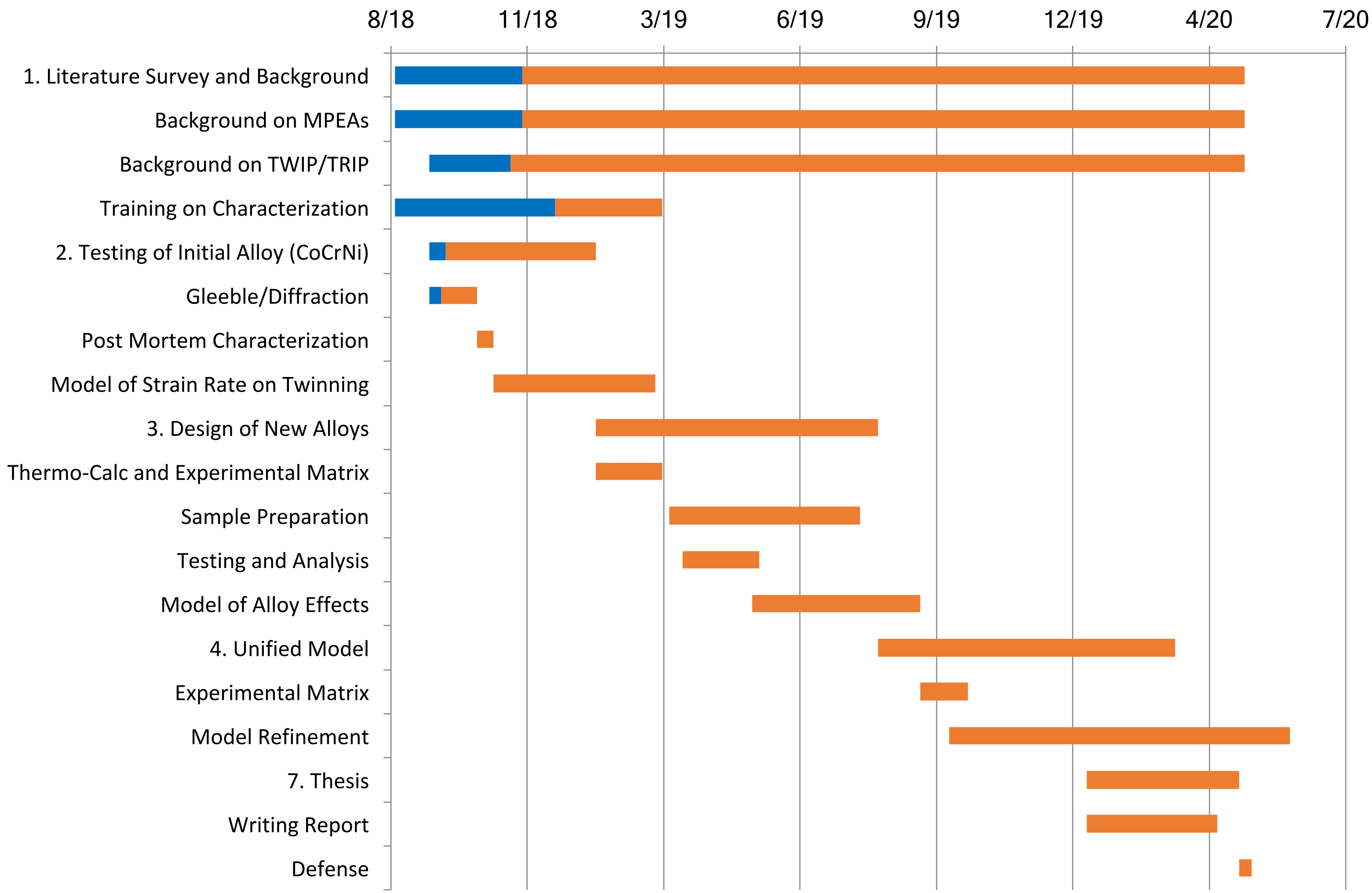


- Initial alloy selected: $Co_{.55}Cr_{.05}Ni_{.40}$
  - Shown to exhibit TRIP/TWIP
  - Quasi-static experimentation next

Conclusions

- In-situ studies of strain rate, strain state and temperature effects on TRIP/TWIP behavior
  - Fundamental understanding of TRIP/TWIP behavior
  - Design of deformation mechanisms through alloy to meet application criteria
  - Low SFE of MPEAs indicates possibility for TWIP/TRIP behavior even at elevated temperatures

Progress


8/18
11/18
3/19
6/19
9/19
12/19
4/20
7/20
1. Literature Survey and Background
Background on MPEAs
Background on TWIP/TRIP
Training on Characterization
2. Testing of Initial Alloy (CoCrNi)
Gleeble/Diffraction
Post Mortem Characterization
Model of Strain Rate on Twinning
3. Design of New Alloys
Thermo-Calc and Experimental Matrix
Sample Preparation
Testing and Analysis
Model of Alloy Effects
4. Unified Model
Experimental Matrix
Model Refinement
7. Thesis
Writing Report
Defense

Thank you very much!

John Copley

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An Industry/University Cooperative Research Center

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Student: *John Copley*

Faculty: *Amy Clarke*

Goals

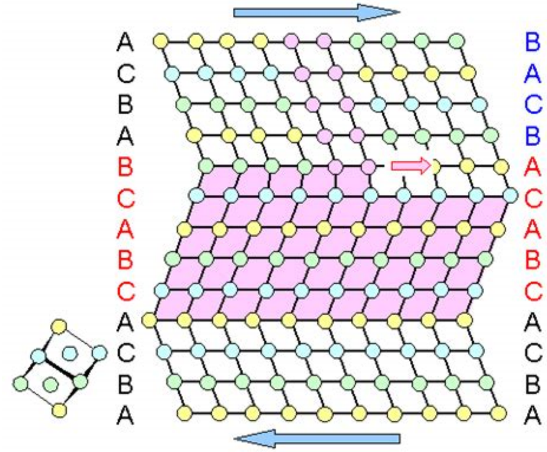
- Modeling of deformation behavior as it pertains to microstructural changes in MPEAs

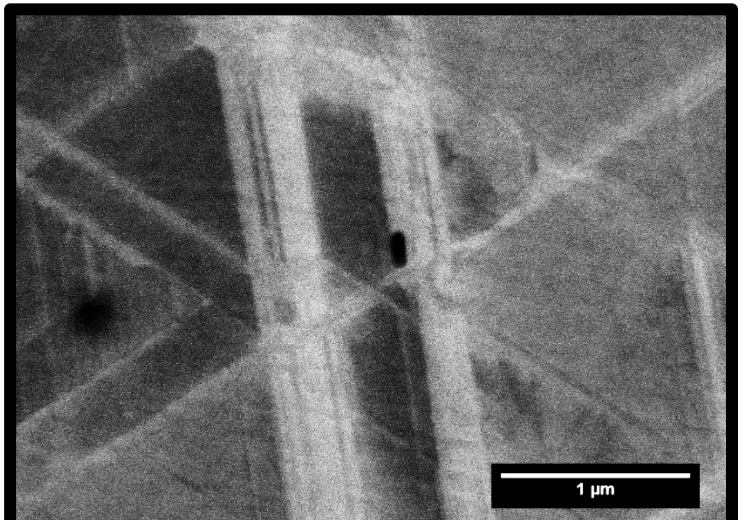
Significance and Impact

- The TRIP/TWIP behavior seen in MPEAs results in high work hardening behavior, resulting in an increased ductility, toughness and blast resistance.

Research Details

- In-situ diffraction tests will show the evolution of deformation twins (a HCP phase in a FCC matrix) which can be compared to the strain rate, strain state and alloy composition to allow alloy design for specific applications





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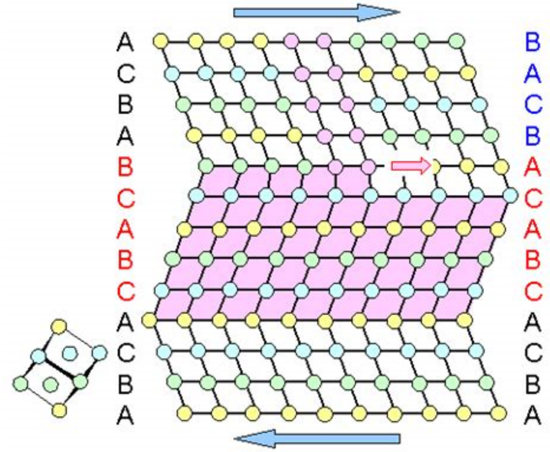

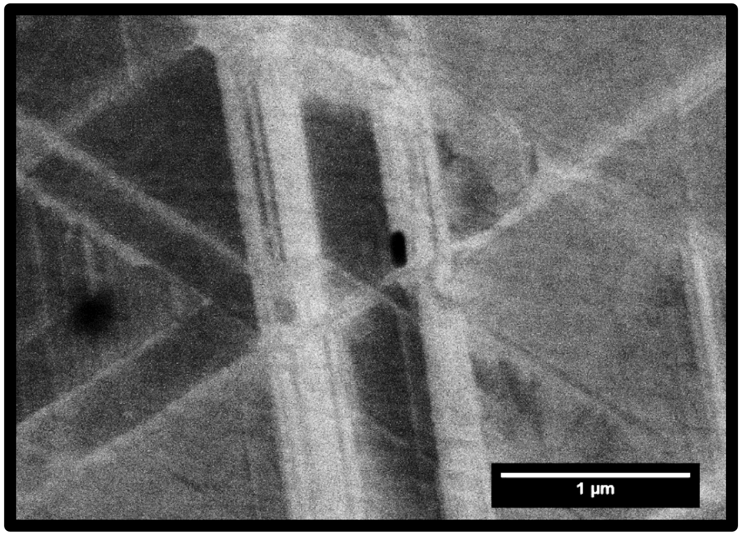

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Student: *John Copley*

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Project Duration: *Sept. 2018 – May 2020*

Program Goal

- Modeling of deformation behavior as it pertains to microstructural changes in MPEAs

Approach

- In-situ diffraction tests will show the evolution of deformation twins (a HCP phase in a FCC matrix) which can be compared to the strain rate, strain state and alloy composition to allow alloy design for specific applications

Benefits

- The TRIP/TWIP behavior seen in some MPEAs results in high work hardening behavior, resulting in an increased ductility, toughness and blast resistance.