TWIP/TRIP assisted quinary HEAs/CCAs: design, microstructure and properties

Max-Planck-Institut für Eisenforschung GmbH

Xiaoxiang Wu, Zhiming Li and Dierk Raabe

Simulation support: Yuji Ikeda, Fritz Körmann, Jörg Neugebauer

x.wu@mpie.de

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Outline

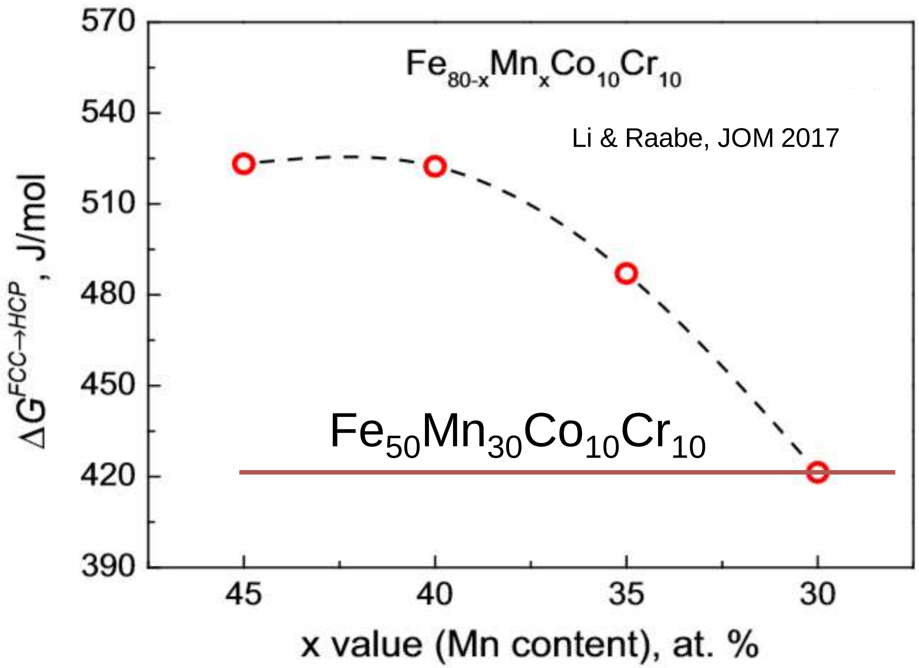
I **Background** – a brief reminder

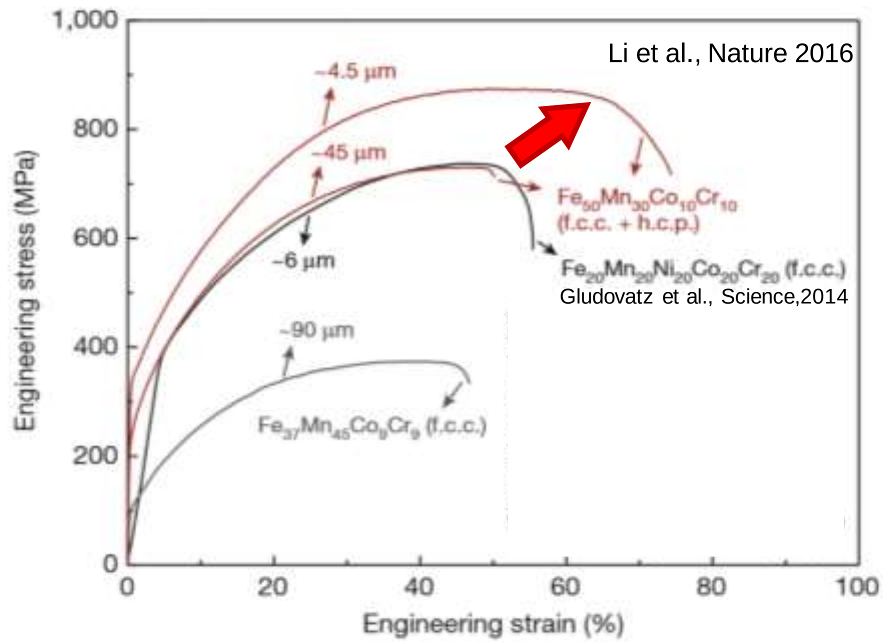
II **Motivation** – what is the target?

III **Experimental** – design and results

IV **Summary and outlook**

Background – Quaternary TRIP CCAs/HEAs





Lower stacking fault energy (SFE)

TRIP: transformation induced plasticity

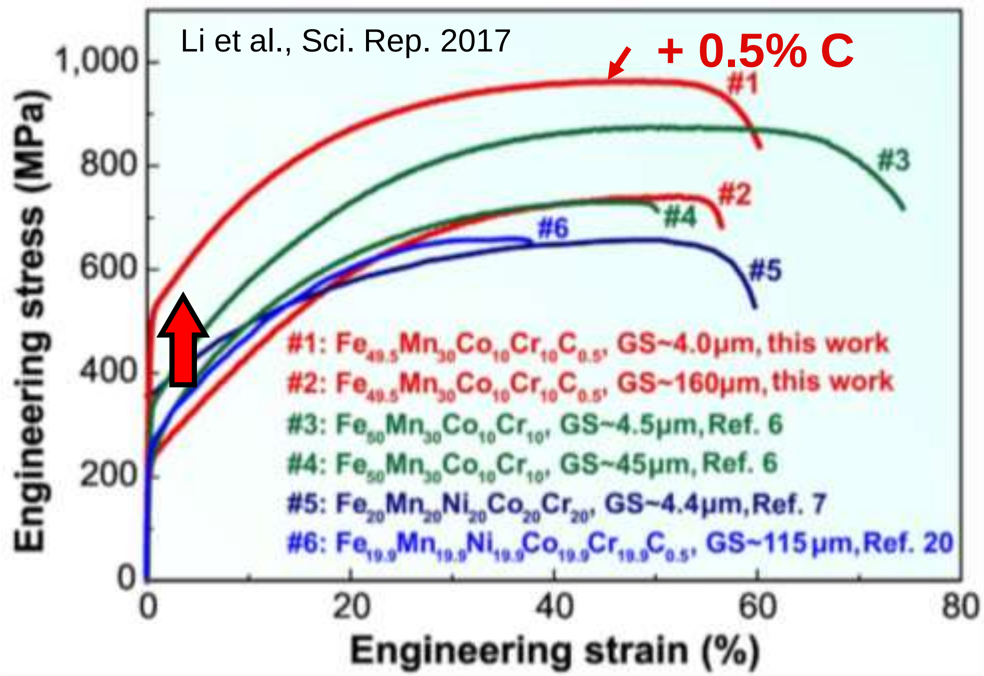
TRIP

TWIP

TWIP: twinning induced plasticity

Improved strength and ductility

Background – Quaternary iCCAs/iHEAs



Interstitial C addition

TRIP

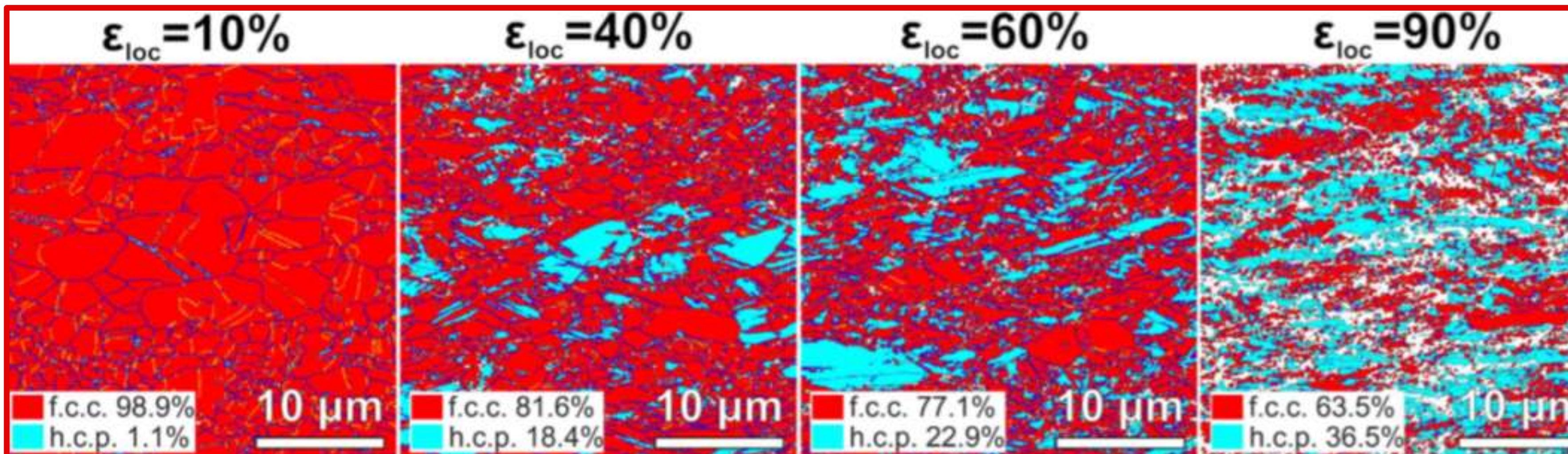
TWIP

Interstitial SSS

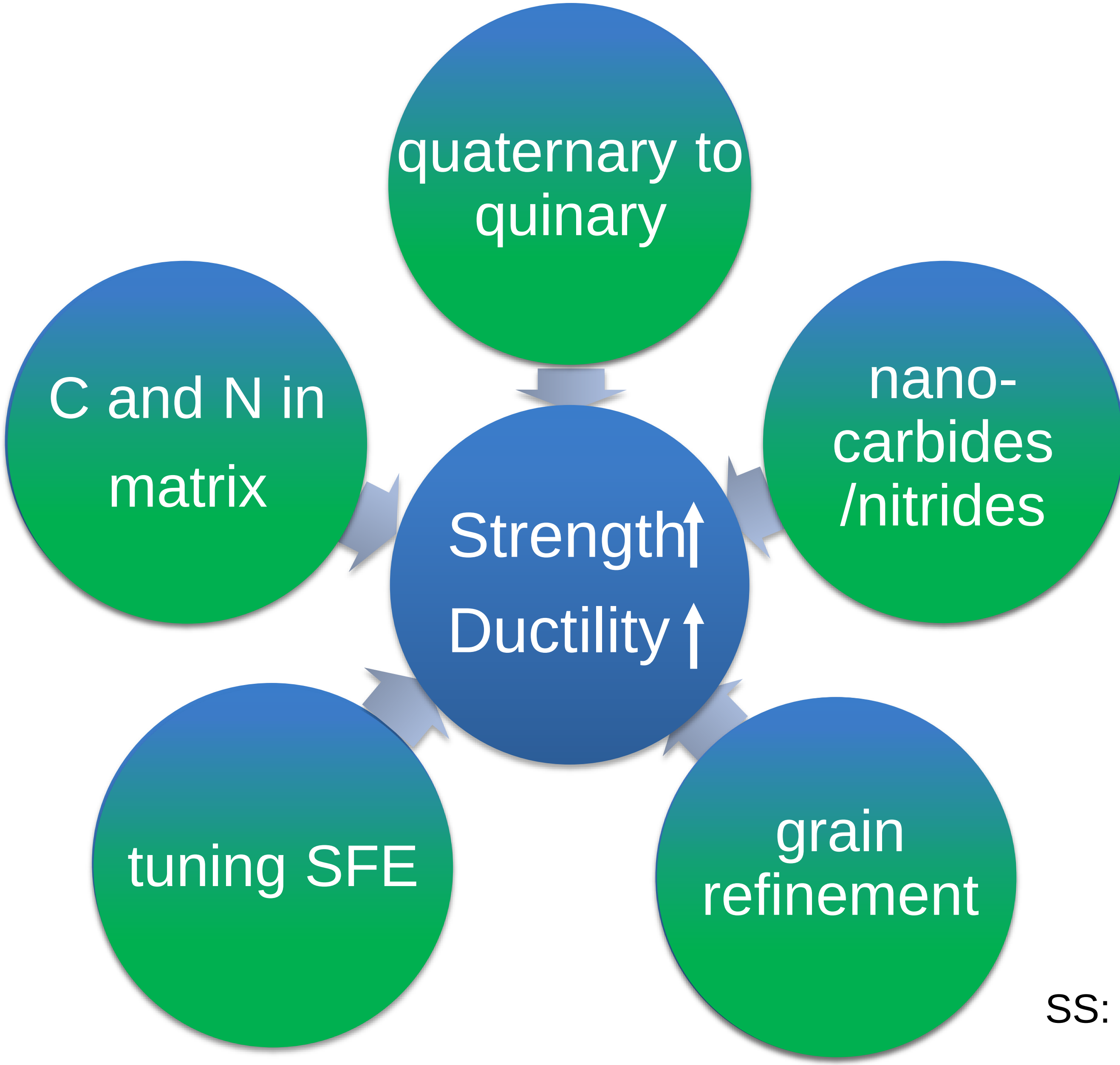
Nano-particles

iCCAs/iHEAs: Improved strength-ductility

SSS: solid solution strengthening

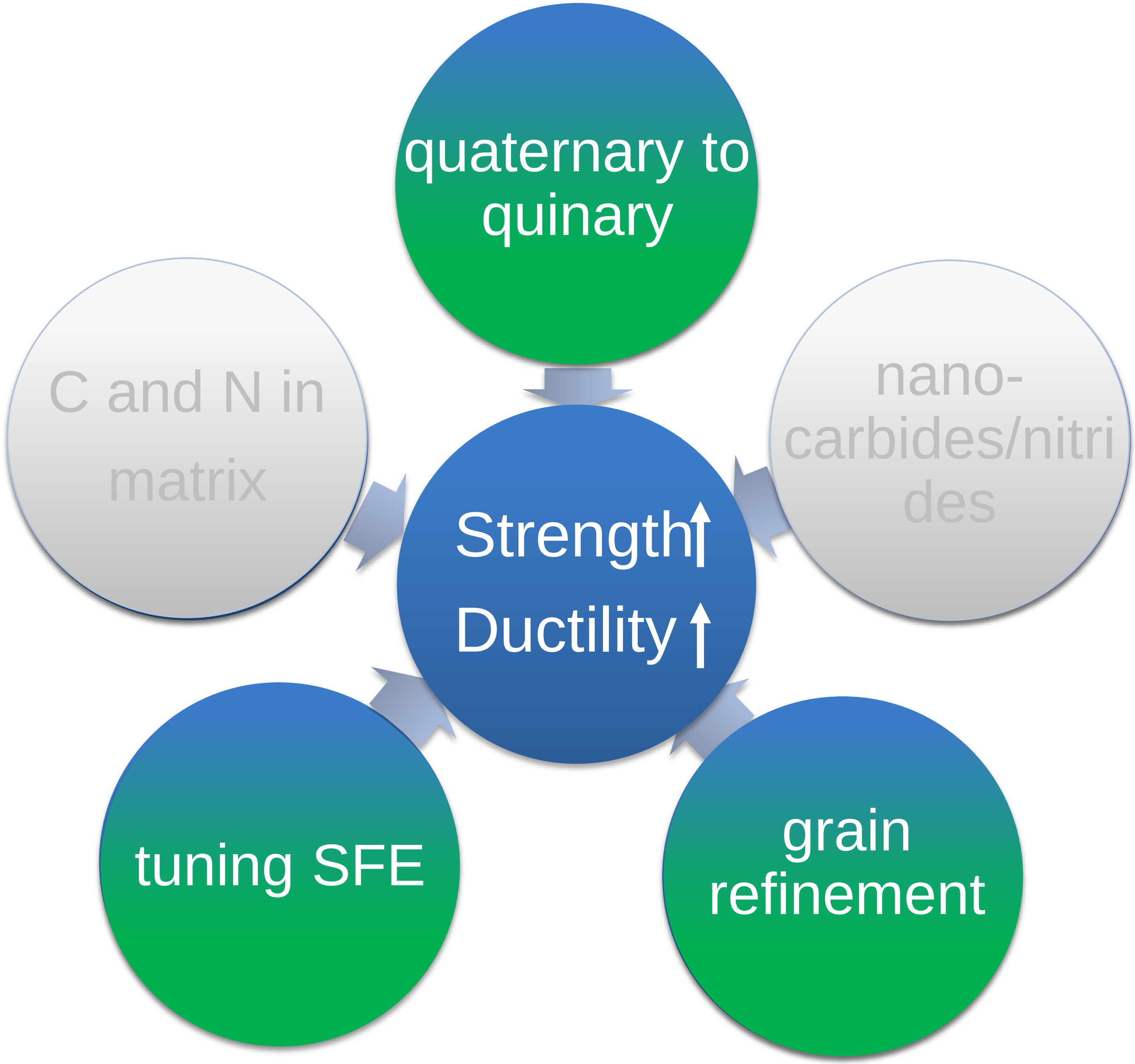


Motivation – what is the target?



SS: solid solution

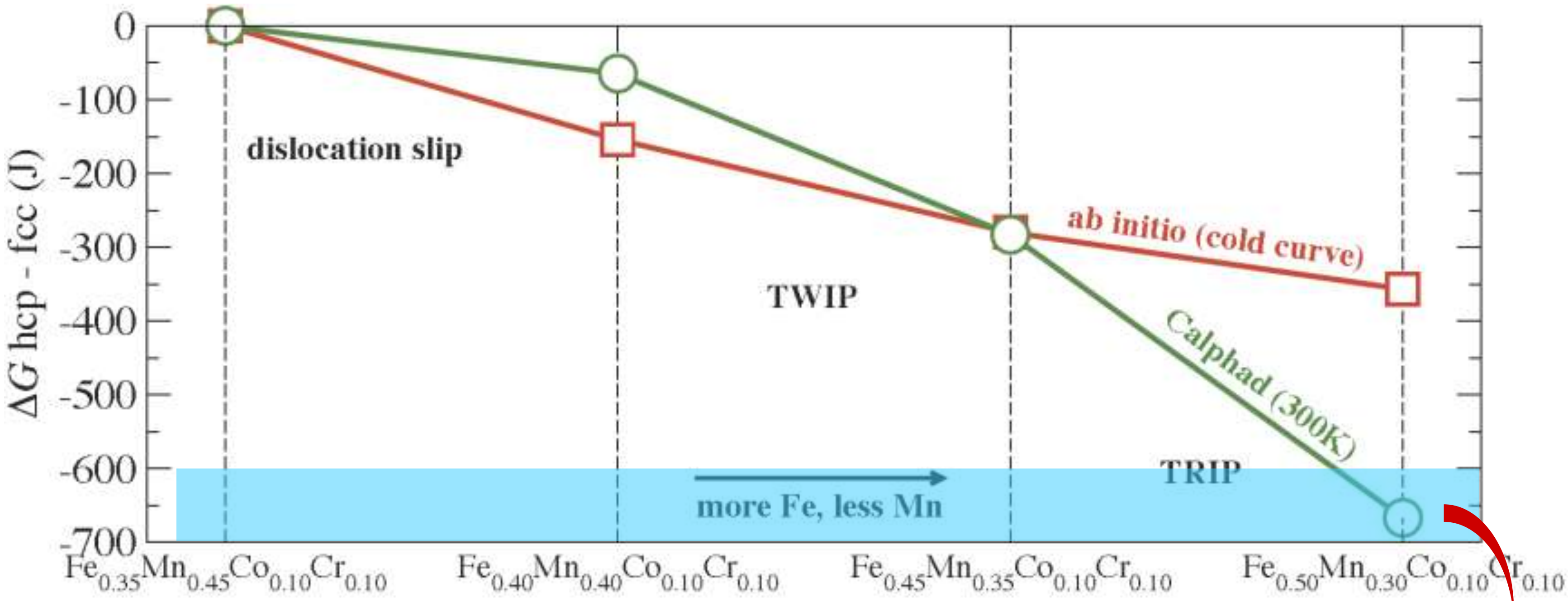
Motivation – first stage



Alloy design – Quinary TRIP CCAs/HEAs

Guiding rule: SFE

→ Quinary CCAs/HEAs with SFE similar to quaternary $Fe_{50}Mn_{30}Co_{10}Cr_{10}$

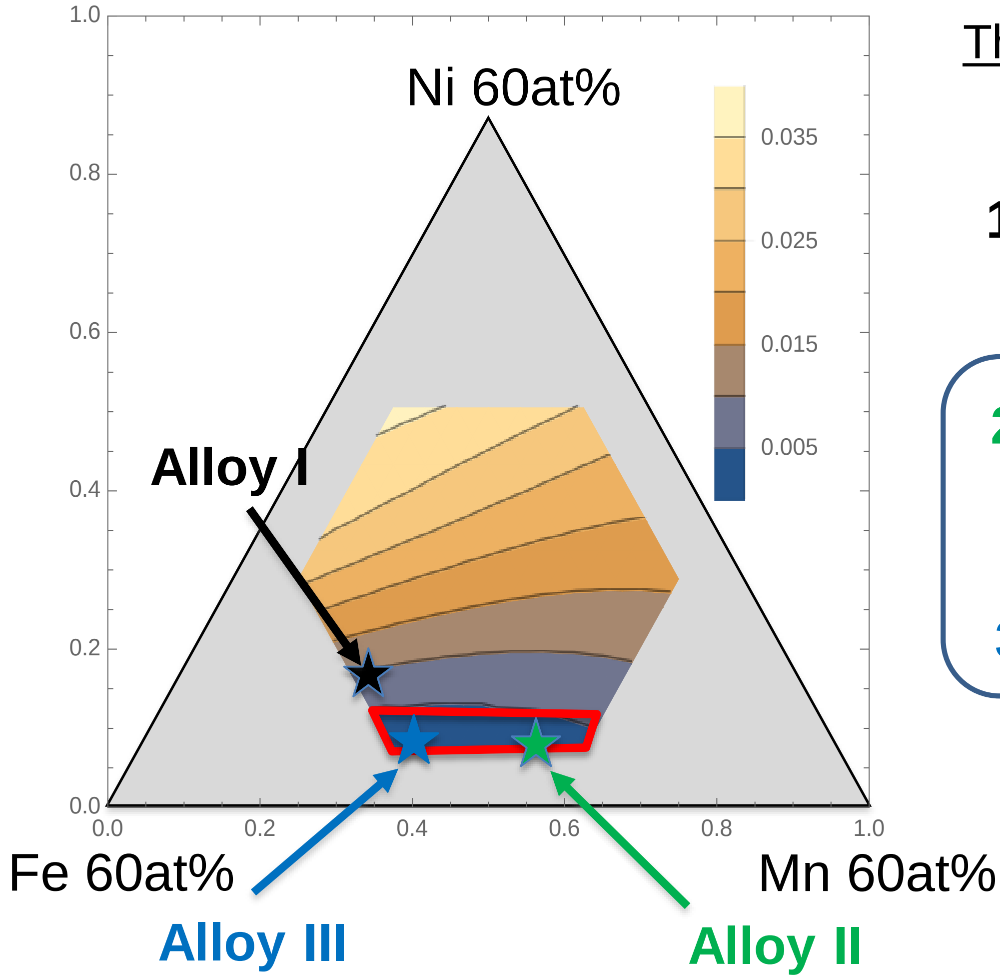


$Co_{20}Cr_{20}Fe_xMn_yNi_z$ (x+y+z=60)

$Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

MPIE: Grabowski, Körmann (unpublished)

Co: 20; Cr: 20; Fe: 5~35; Mn: 5~35; Ni: 5~35



Three alloy systems under investigation:

1. $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

2. $Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_{6}$

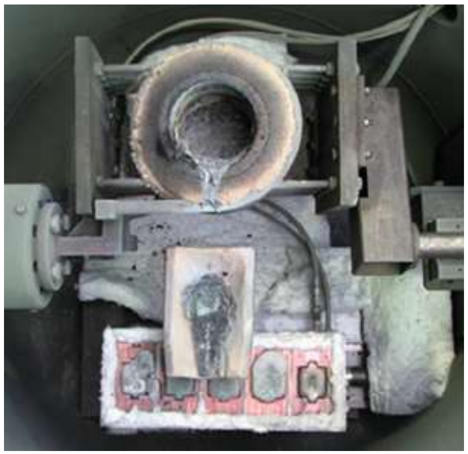
3. $Co_{20}Cr_{20}Fe_{24}Mn_{30}Ni_{6}$

Input from *ab initio* calculation

Experimental – alloy fabrication

Set 1: coarse grains

Casting → Hot rolling @900°C → Homogenization @1200°C, 2h → Water-quenching (WQ)



Ingot size: 10×50×150 mm³

50% thickness reduction,

10 mm → 5 mm

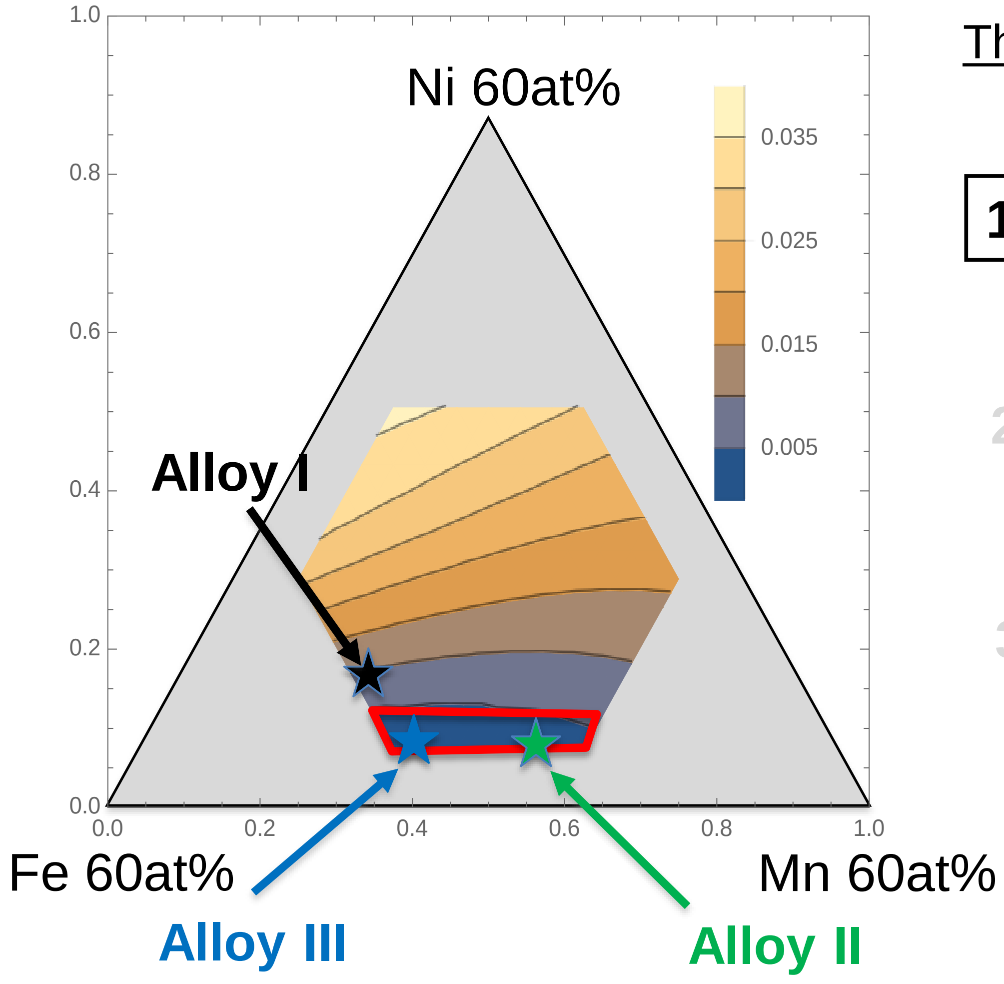
Set 2: refined grains

Homogenized state → Cold rolling 5 mm → 1.5 mm →

- Annealing @900°C, 5min, Ar, WQ
- Annealing @800°C, 10 min, Ar, WQ

Alloy design – Quinary TRIP CCAs/HEAs

Co: 20; Cr: 20; Fe: 5~35; Mn: 5~35; Ni: 5~35



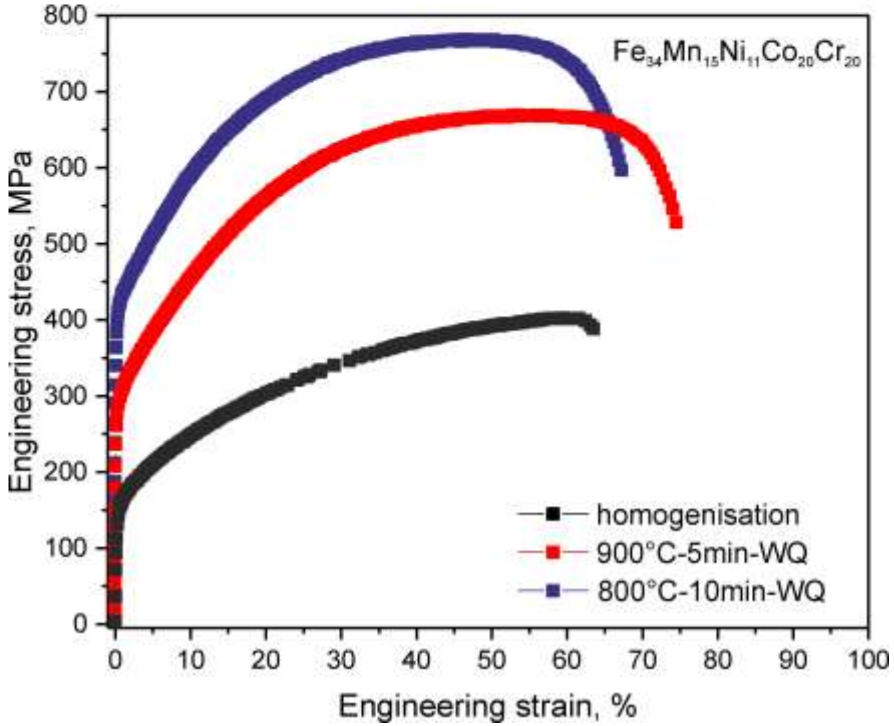
Three alloy systems under investigation:

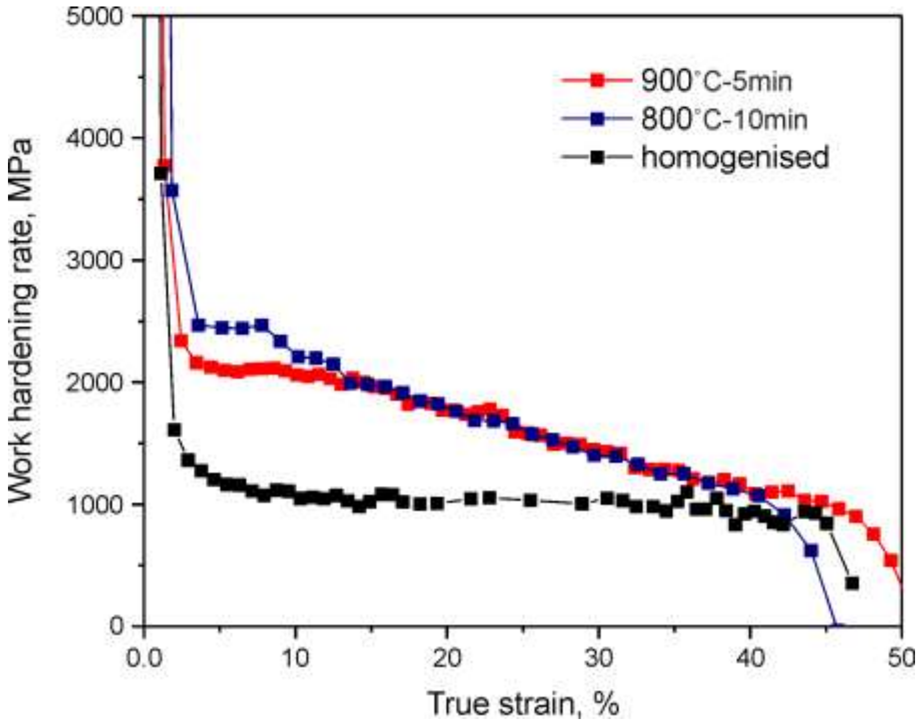
1. $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

2. $Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_{6}$

3. $Co_{20}Cr_{20}Fe_{24}Mn_{30}Ni_{6}$

$Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$ – tensile properties of samples from different heat treatment conditions



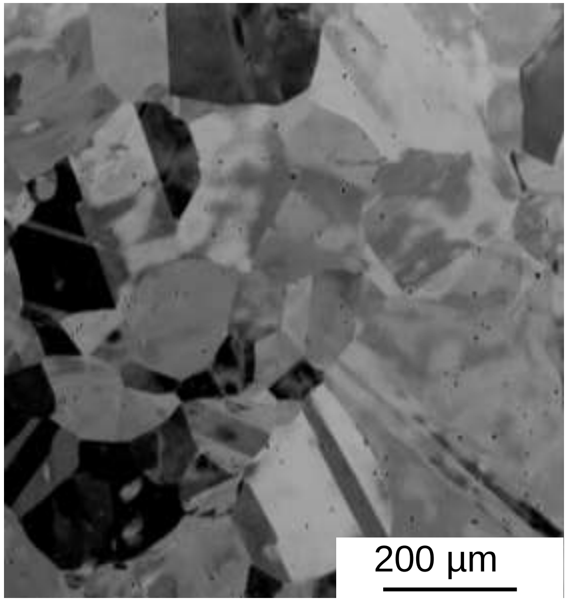


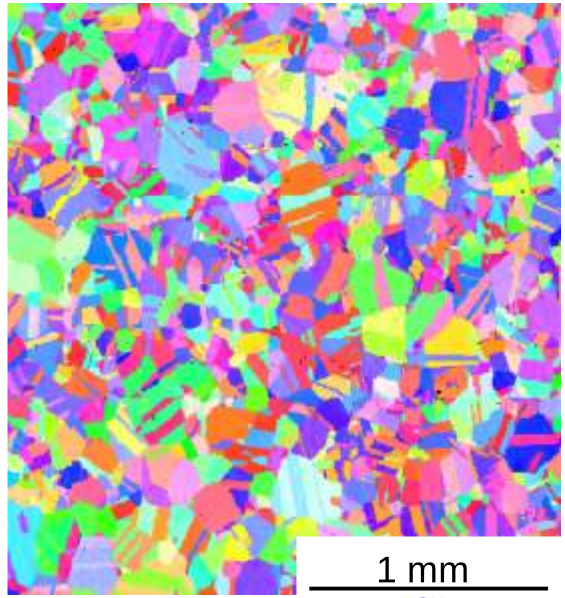
$Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

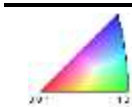
1. Coarse grain alloy has reasonable strength and good ductility.
2. Grain refinements lead to a simultaneous increase of strength and ductility.

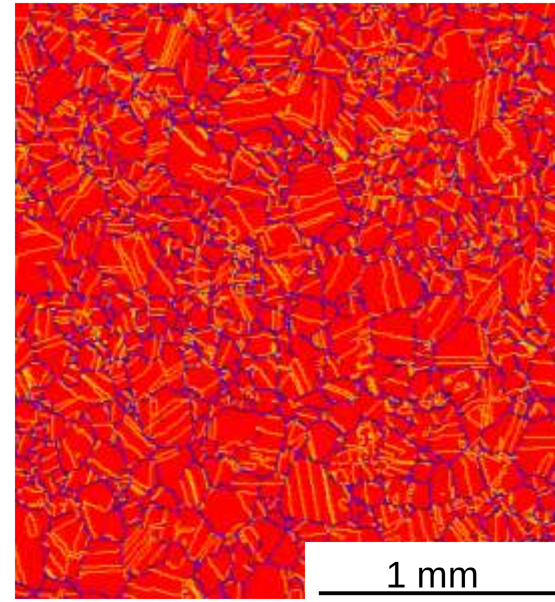
Experimental – alloy I: $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

I. Homogenized state @1200°C, 2h

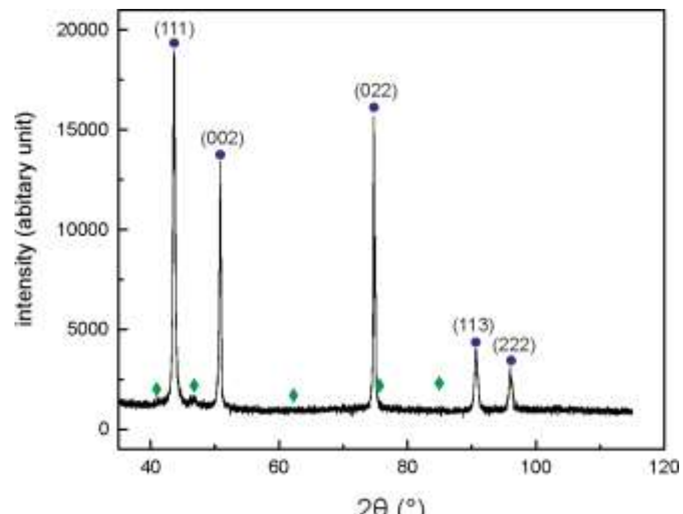






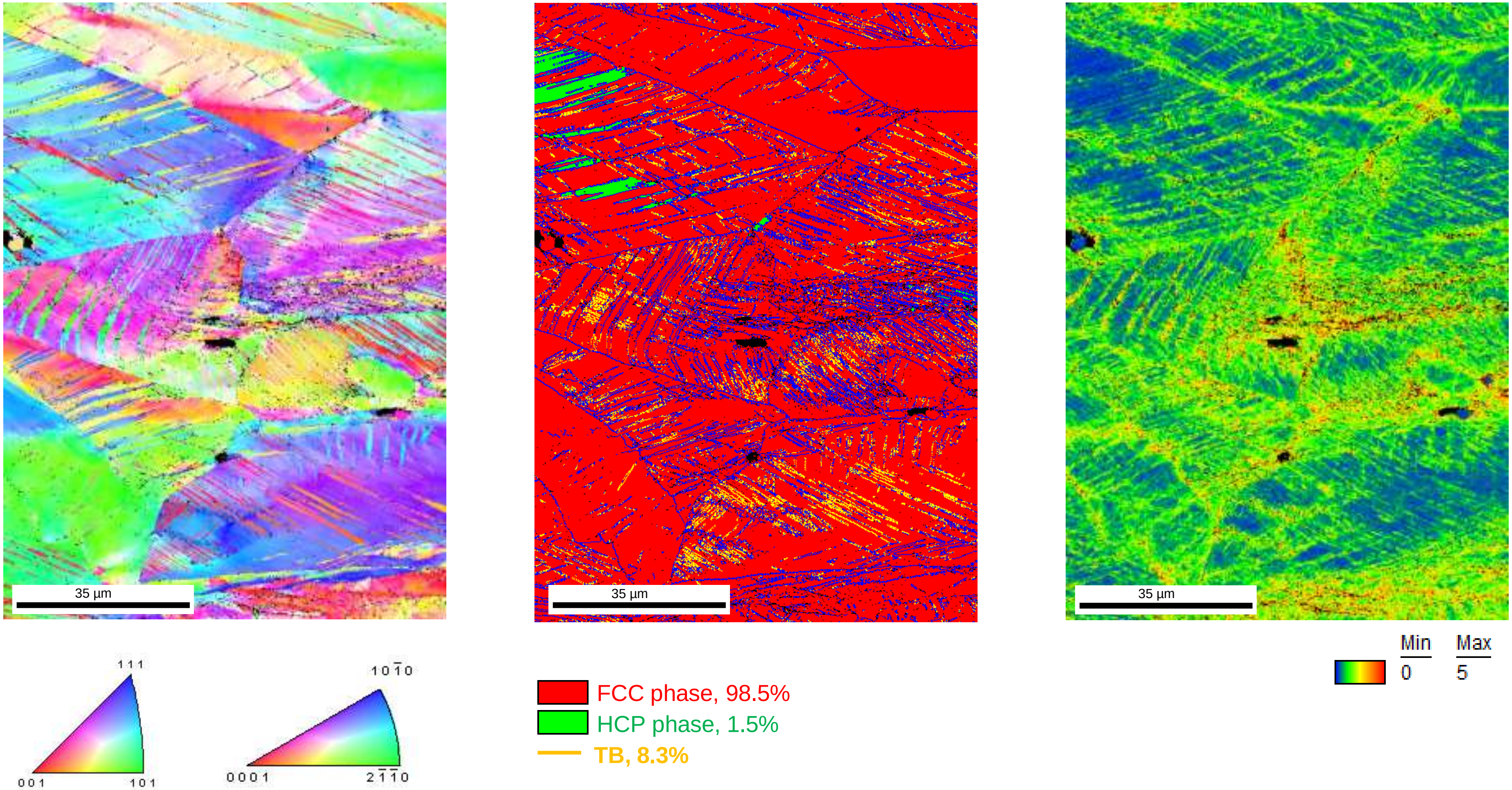


- Single FCC phase
- High fraction of annealing twins (~47% twins)
- Average grain size ~156 µm



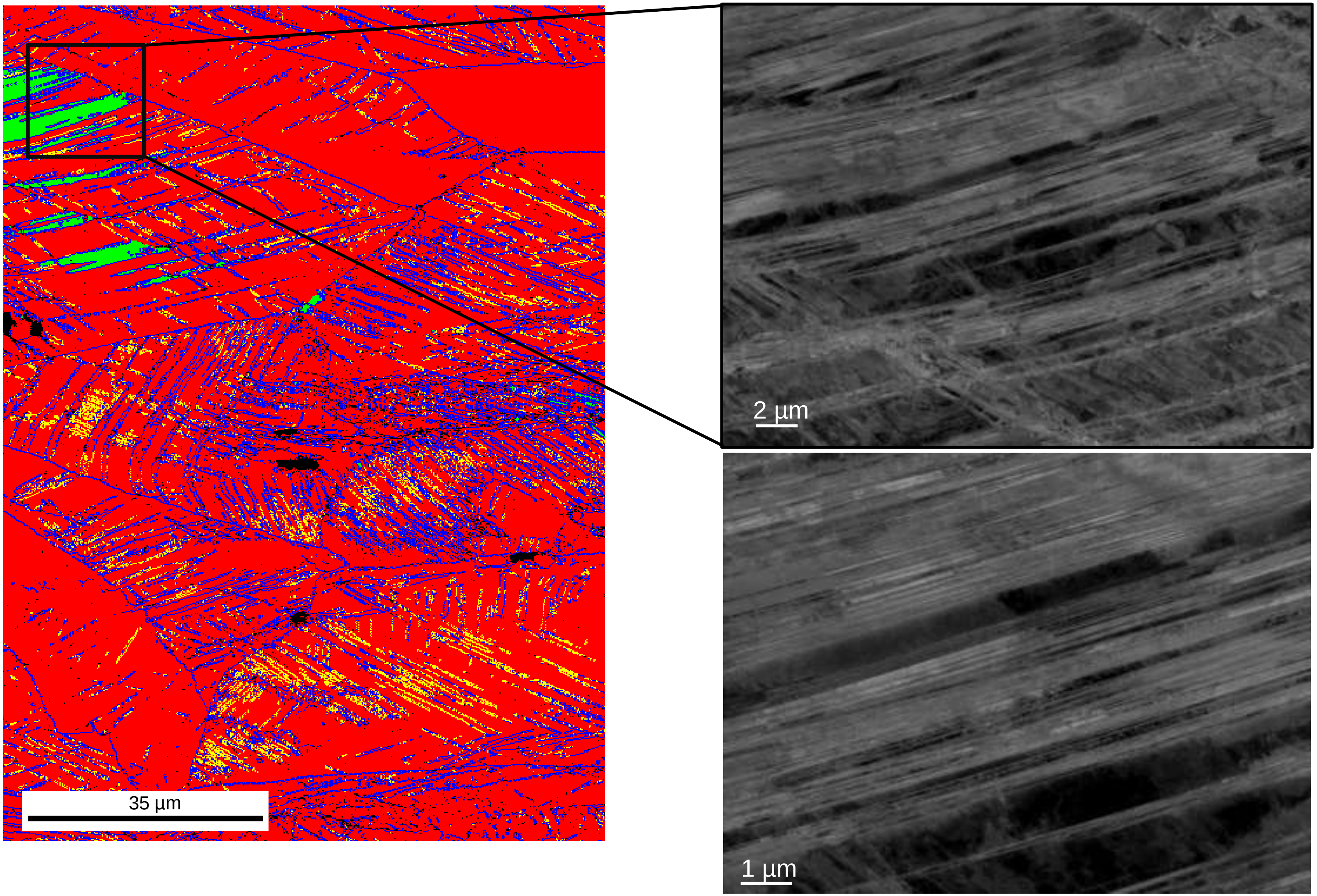
Experimental – alloy I: $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

Microstructure: homogenized state @80% tensile strain (local strain)



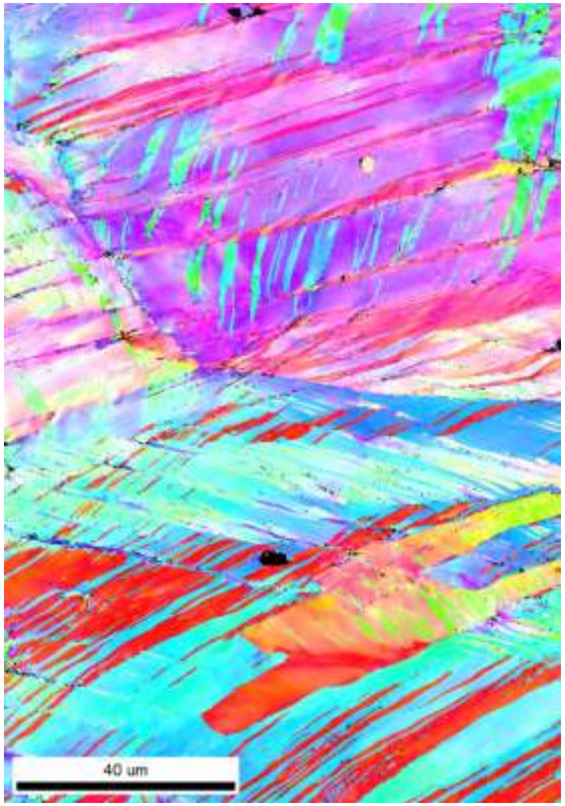
For $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$ alloy, TRIP effect is observed, but TWIP is dominant.

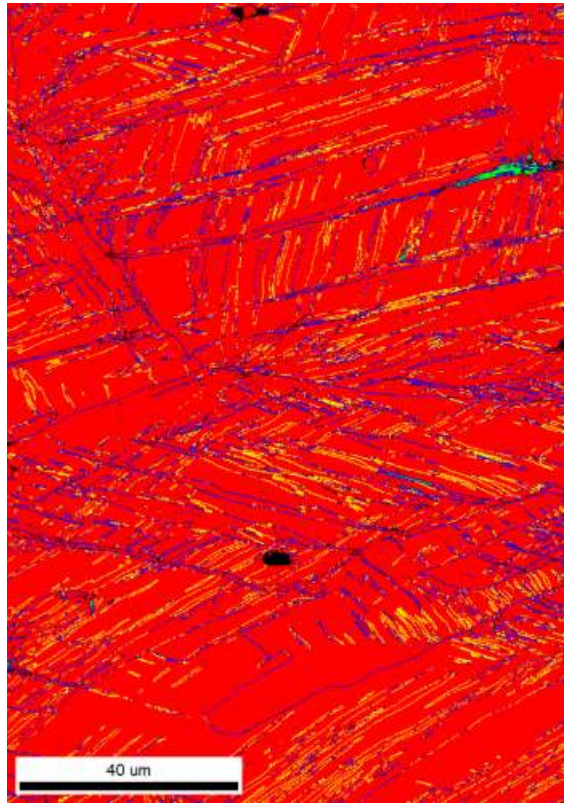
I. Homogenized state @80% tensile strain (local strain)

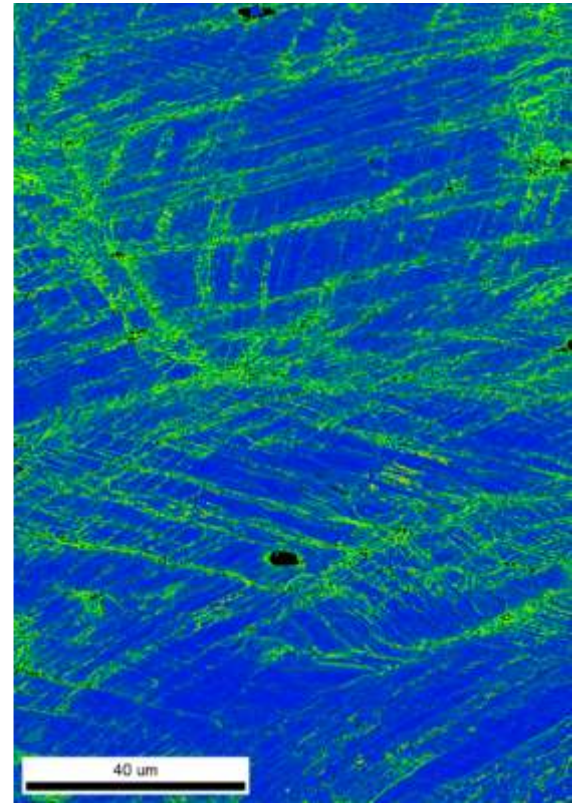


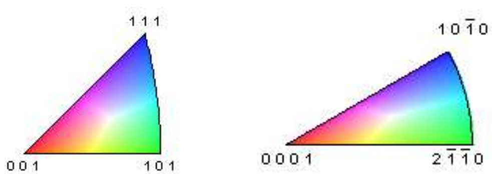
Experimental – alloy I: $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

I. Homogenized state @ 60% tensile strain (local strain)









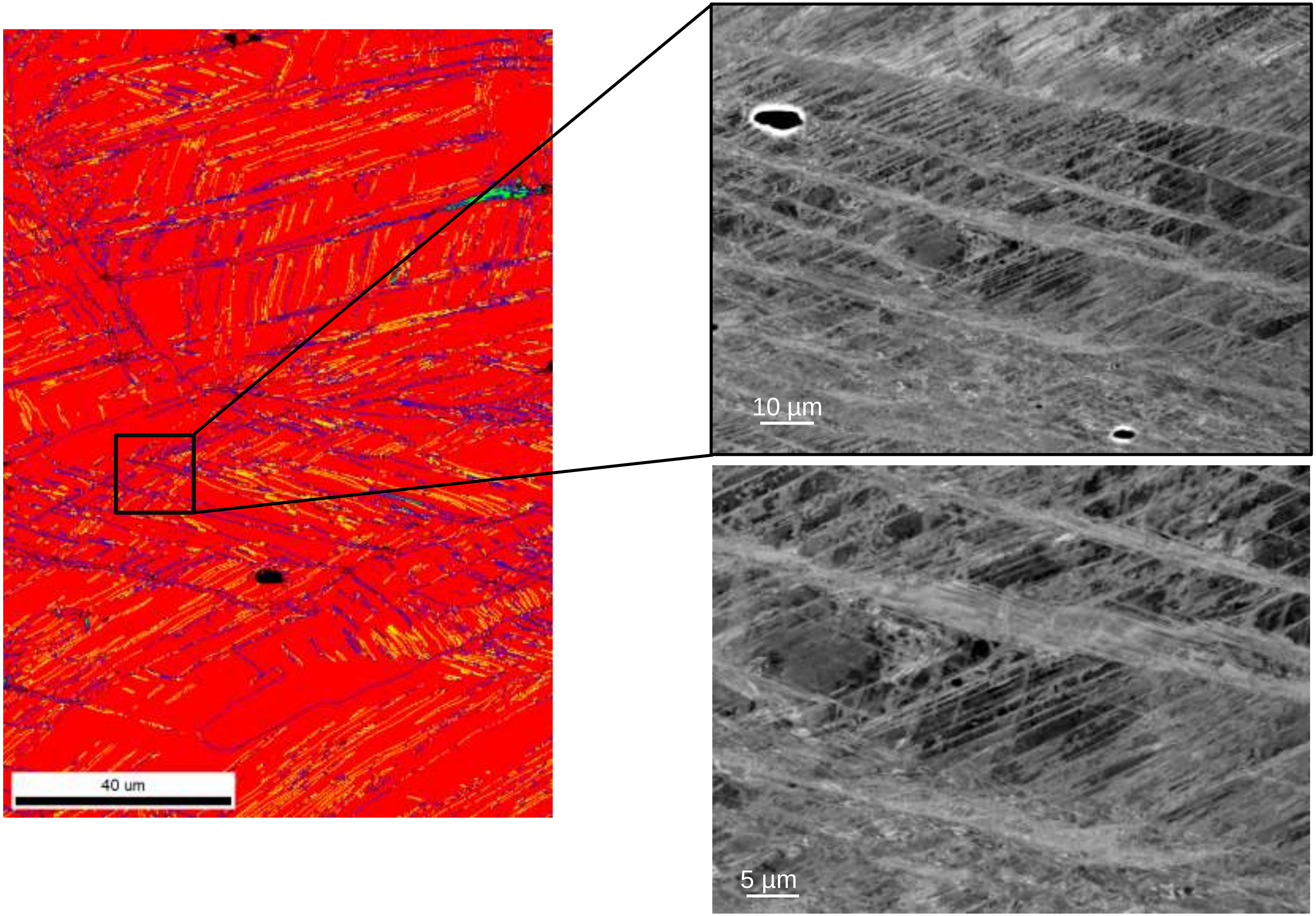
FCC phase, 99.7%
HCP phase, 0.3%
TB

Min 0 Max 5

At lower strains, TRIP effect is neglectable, and TWIP is dominant.

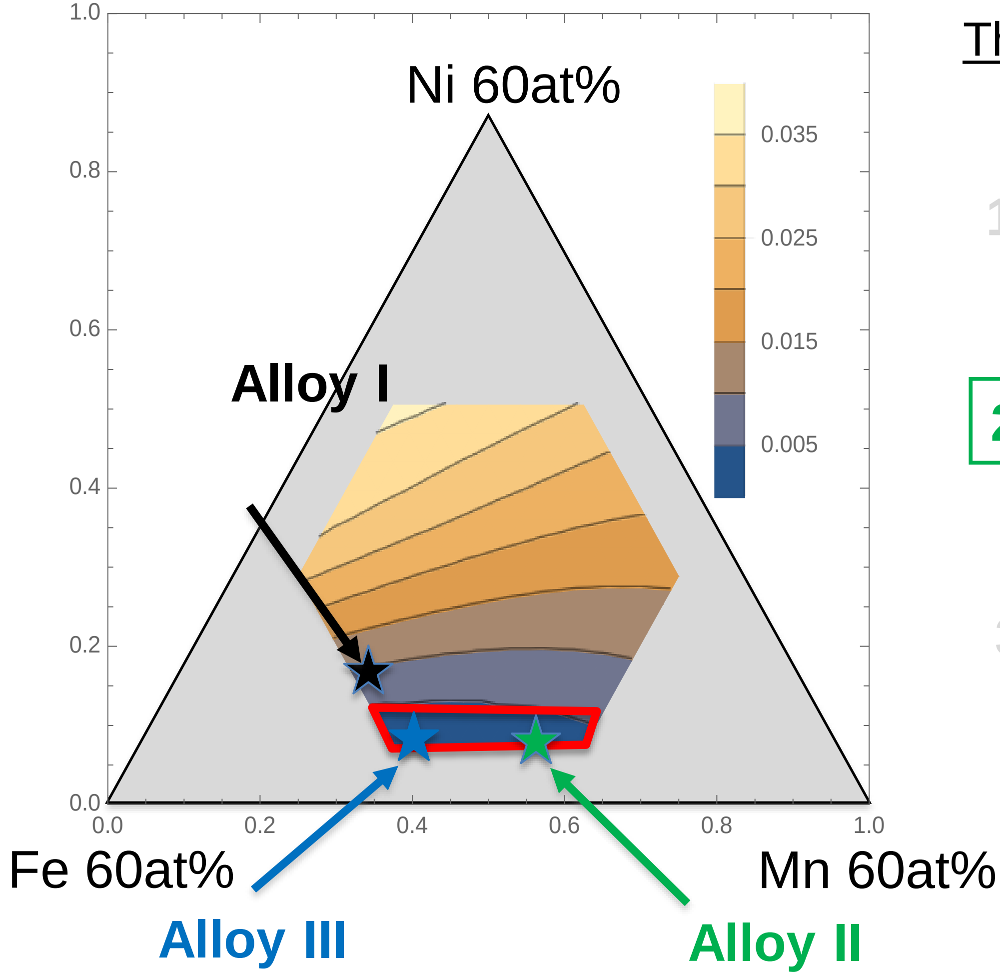
Experimental – alloy I: $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

I. Homogenized state @ 60% tensile strain (local strain)



Alloy design – Quinary TRIP CCAs/HEAs

Co: 20; Cr: 20; Fe: 5~35; Mn: 5~35; Ni: 5~35



Three alloy systems under investigation:

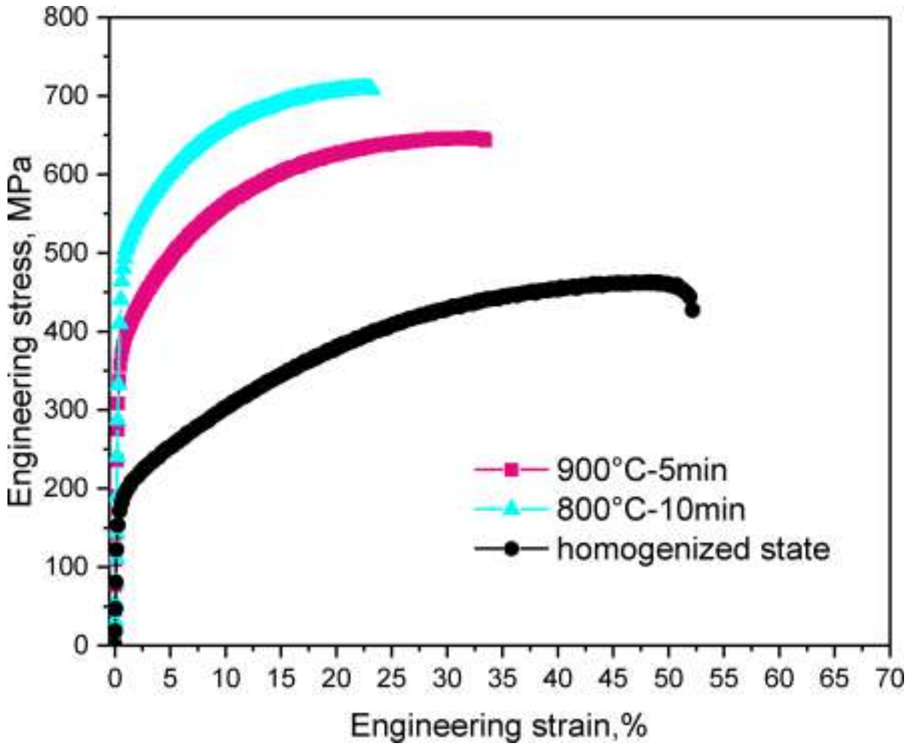
1. $Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

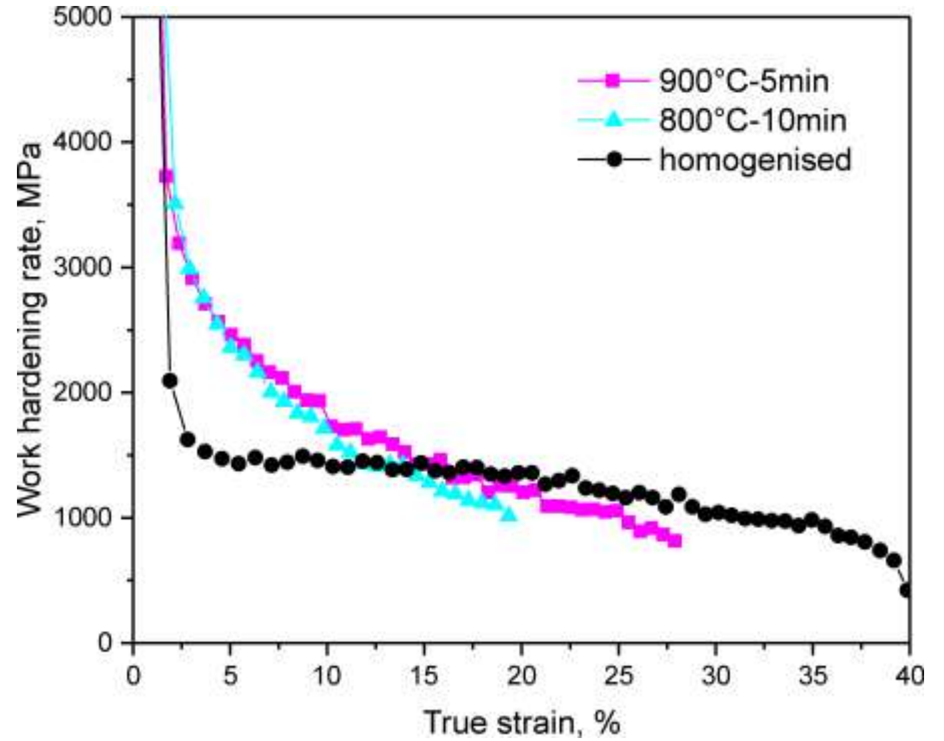
2. $Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_{6}$

3. $Co_{20}Cr_{20}Fe_{24}Mn_{30}Ni_{6}$

Experimental – alloy II: $Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_6$

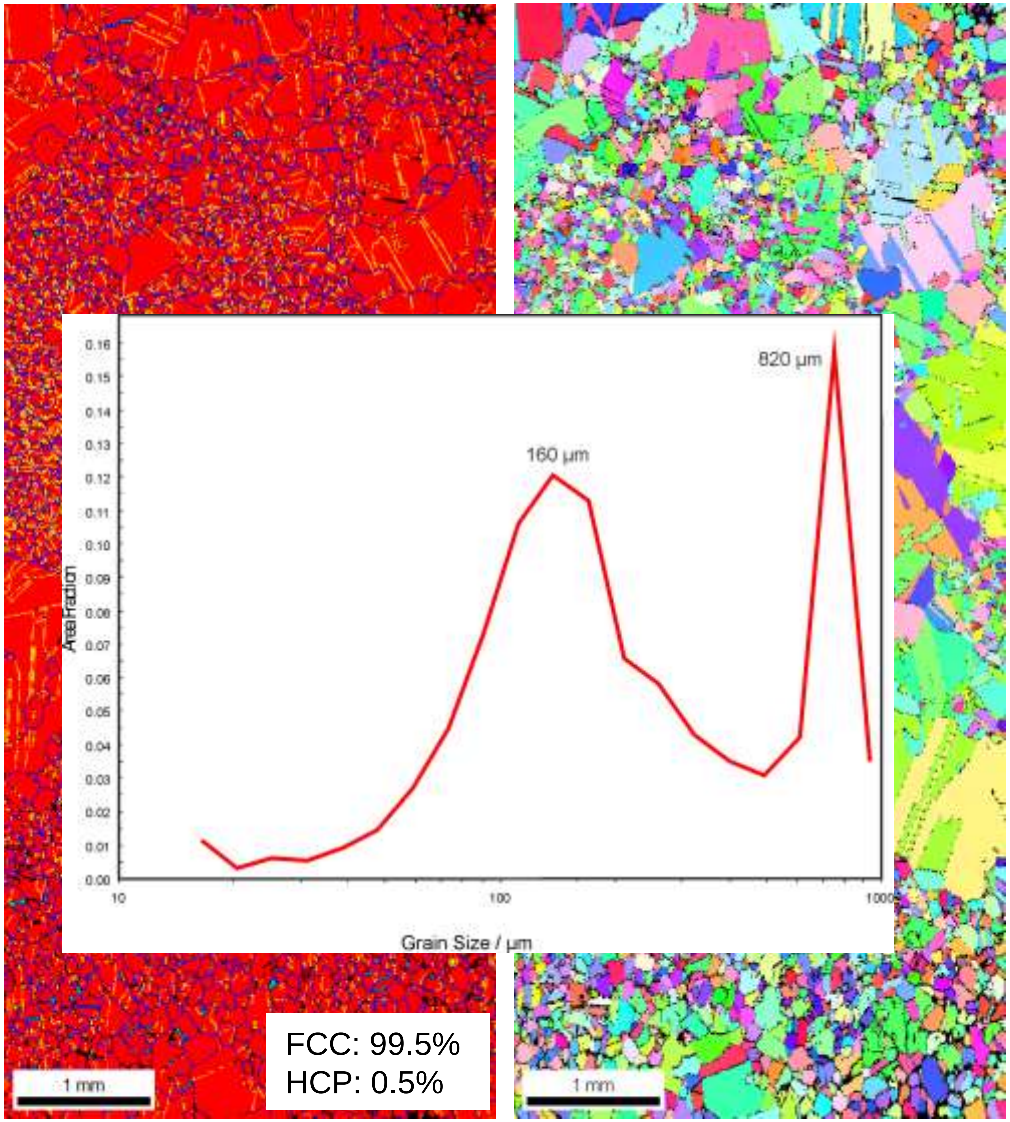
$Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_6$ – tensile properties of samples from different heat treatment

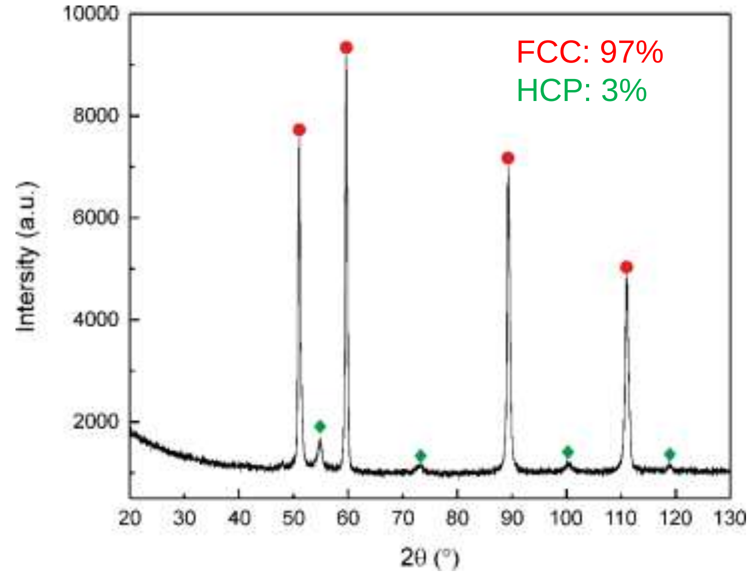




1. Alloy II ($Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_6$) has higher strength but lower ductility compared to Alloy I ($Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$).
2. Grain refinements lead to a significant increase of strength but a decrease of ductility.

II. Homogenized state @1200°C, 2h before DIC test

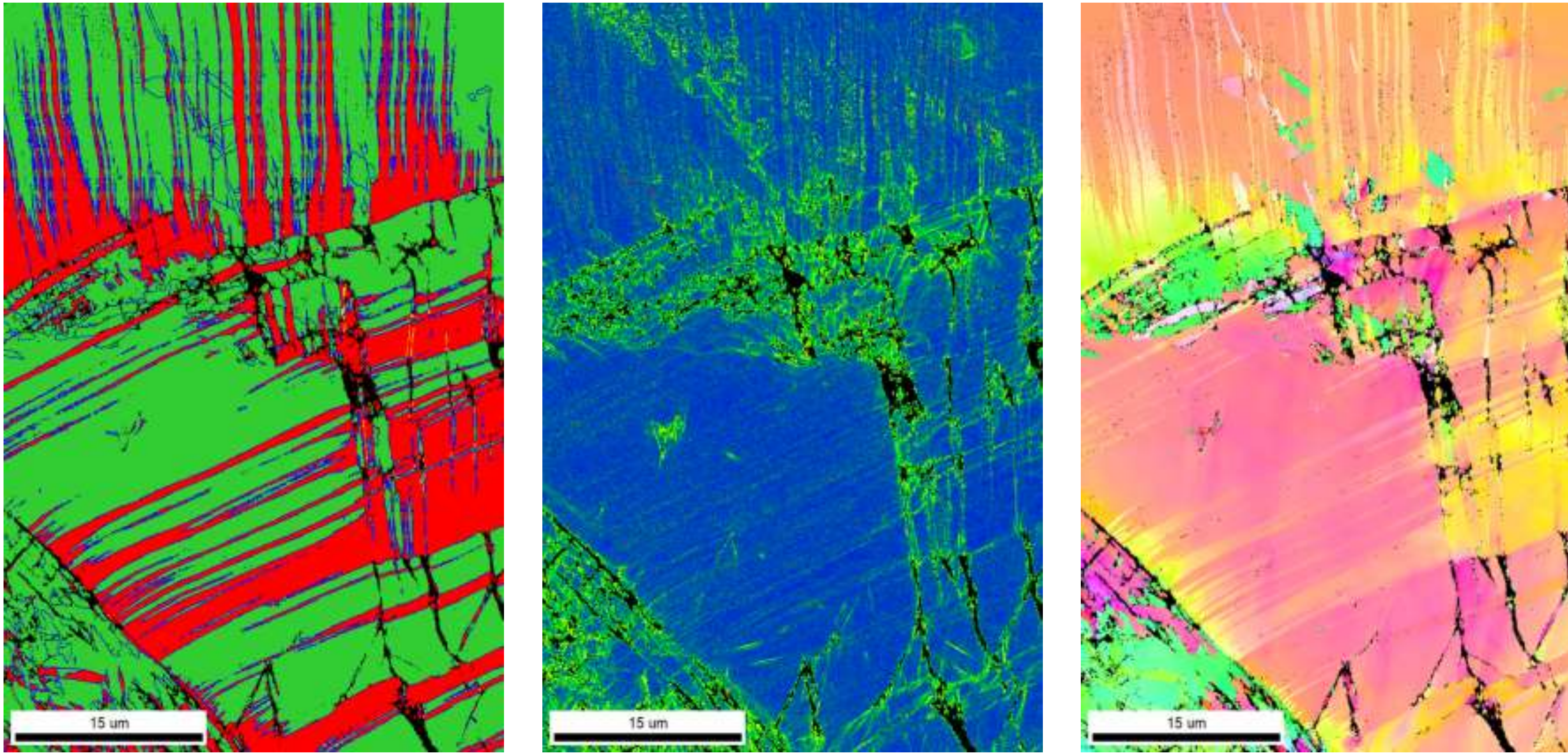




- Dual phase material, with a tiny fraction of HCP
- A high twinning fraction: 39.1%
- Bimodal grain size
- Average grain size ~57.6 µm

Experimental – alloy II: $Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_6$

II. Homogenized state @1200°C, 2h, microstructure after DIC, 40% strain

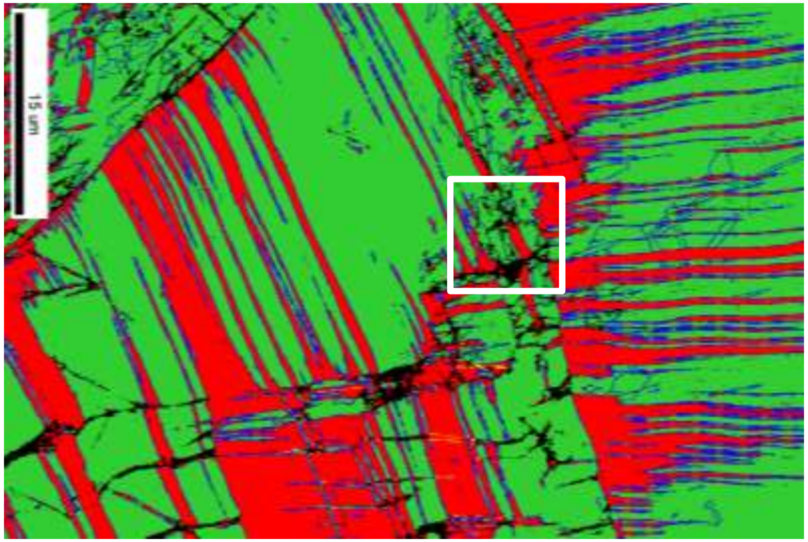


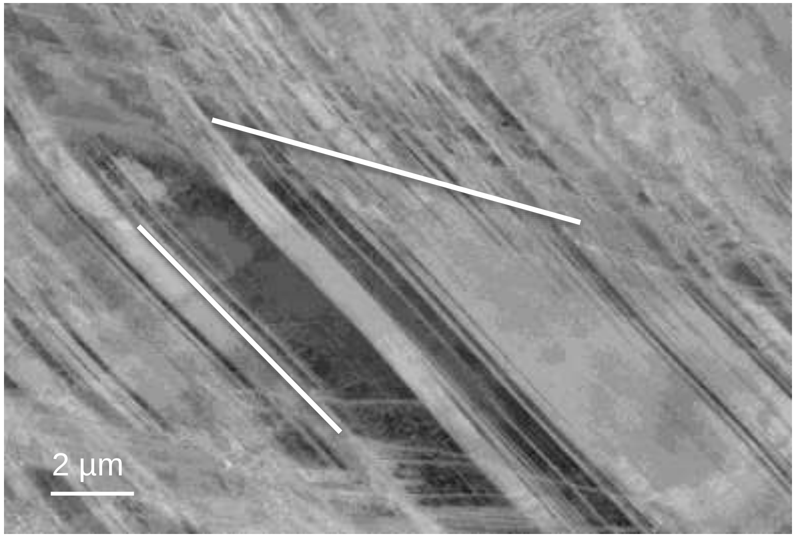
FCC phase, 32.9%
HCP phase: 67.1%
TB

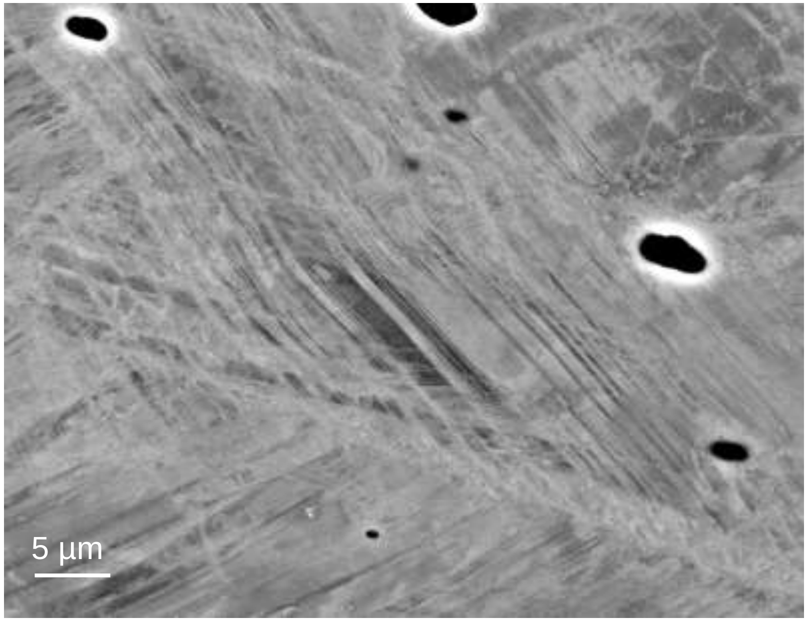
For alloy II, at intermediate strain, TRIP effect is dominant, and TWIP is neglectable.

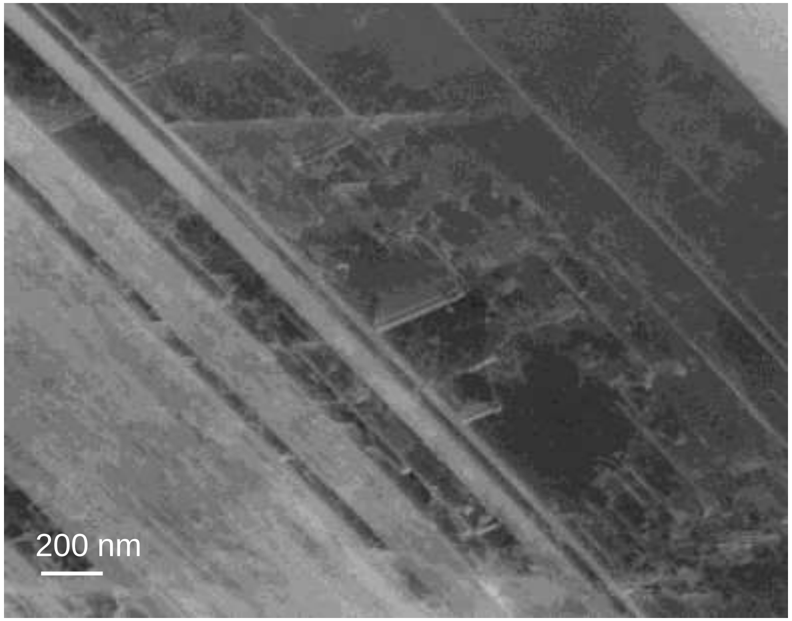
Experimental – alloy II: $Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_6$

II. Homogenized state @1200°C, 2h, microstructure after DIC, 40% strain

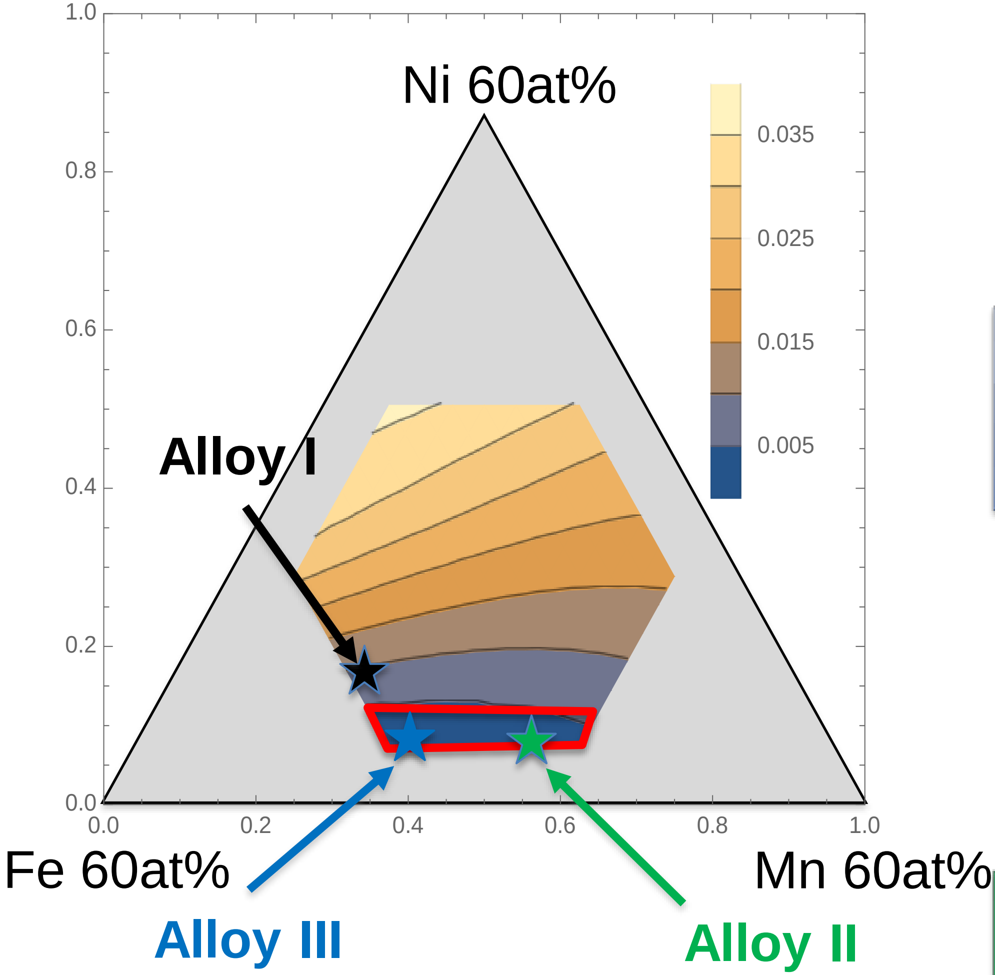








Summary and Outlook



For alloy I:
$Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

Grain refinement leads to a **simultaneous increase** of strength and ductility.

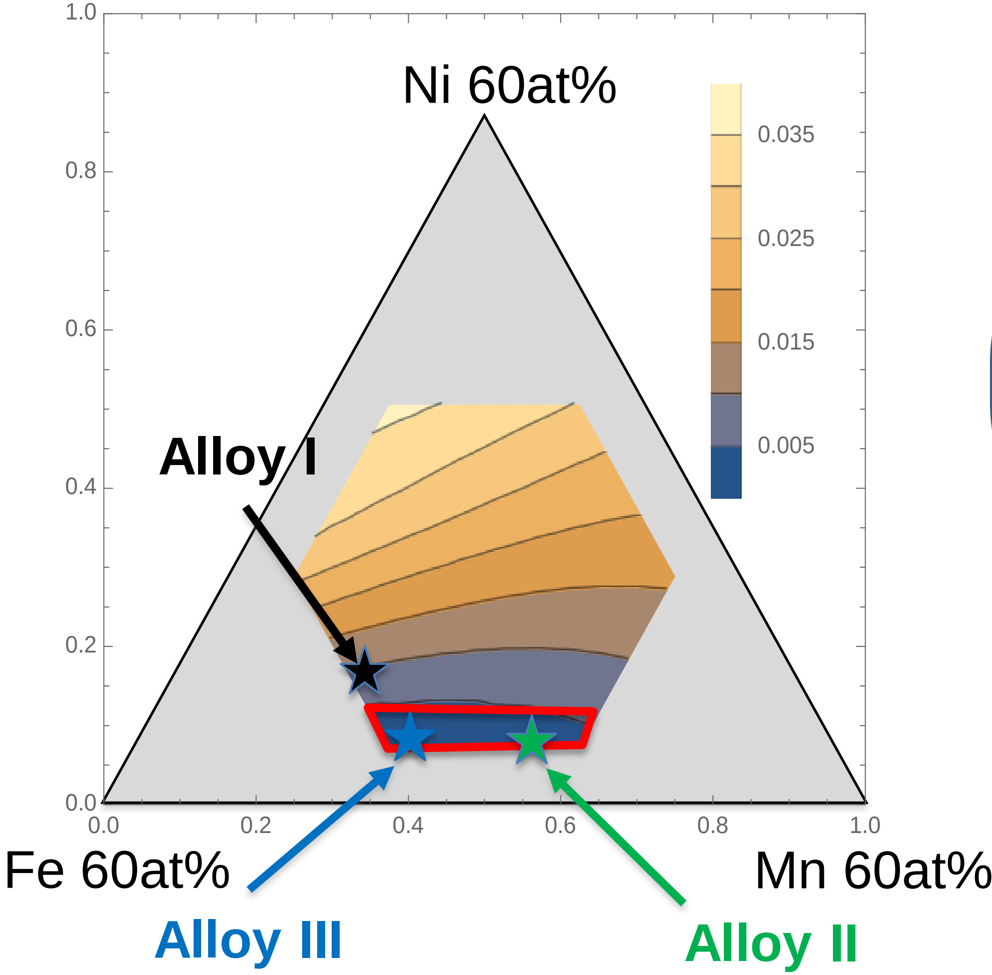
TWIP effect is dominant for homogenized deformation state.

For alloy II:
$Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_{6}$

Grain refinement **doesn't** simultaneously increase strength and ductility.

TRIP effect is dominant for homogenized deformation state.

Summary and Outlook



For alloy I:
$Co_{20}Cr_{20}Fe_{34}Mn_{15}Ni_{11}$

- TRIP *VS.* TWIP
- Deformation mechanism comparison

For alloy II:
$Co_{20}Cr_{20}Fe_{30}Mn_{24}Ni_6$

Adding C or N

similar SFE, different mechanical behavior?

For alloy III:
$Co_{20}Cr_{20}Fe_{24}Mn_{30}Ni_6$

Thank you
for your attention!