# Polycrystalline High Entropy Superalloys (PHESA) -

## Combining novel strengthening mechanisms in compositionally complex CoNiCr-based superalloys with a large fraction of multicomponent intermetallic precipitates

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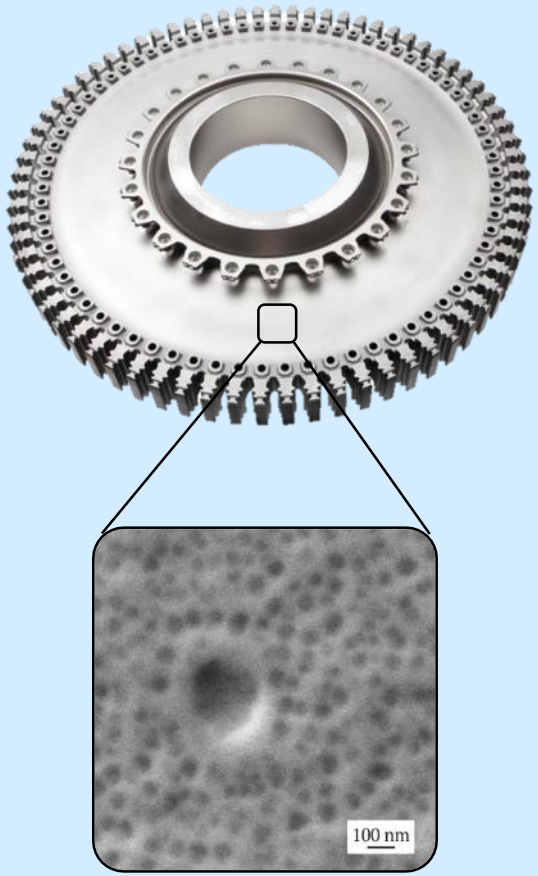
**Materials Science & Engineering, Institute I**

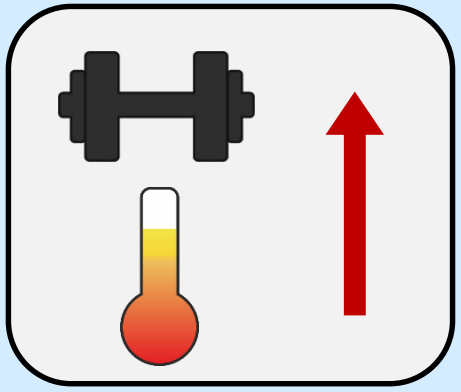
# Wrought Co-base Superalloys as Potential New Turbine Disc Alloys

Ni-base turbines disc

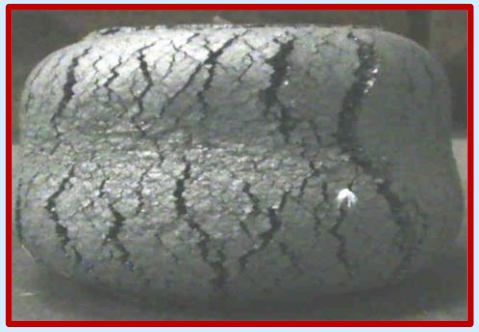



[https://aviationweek.com/optimizing-engines-through-lifecycle/what-consider-when-purchasing-used-llp-parts]

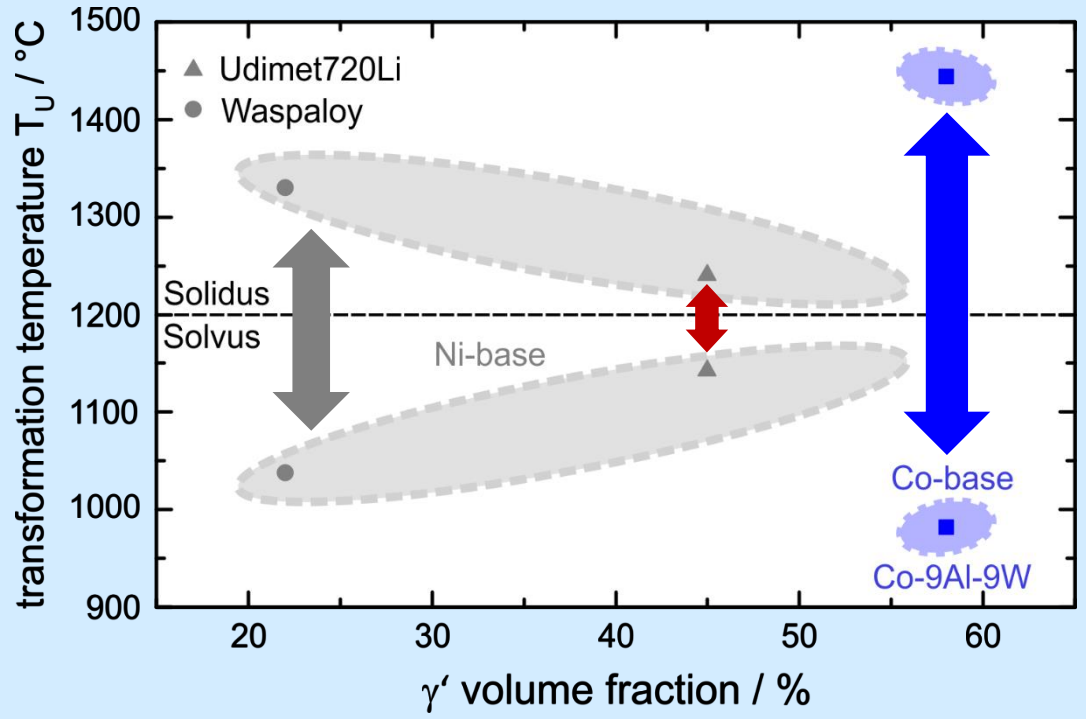
Increasing requirements



Insufficient formability



Devaux et al. (2012), Superalloys

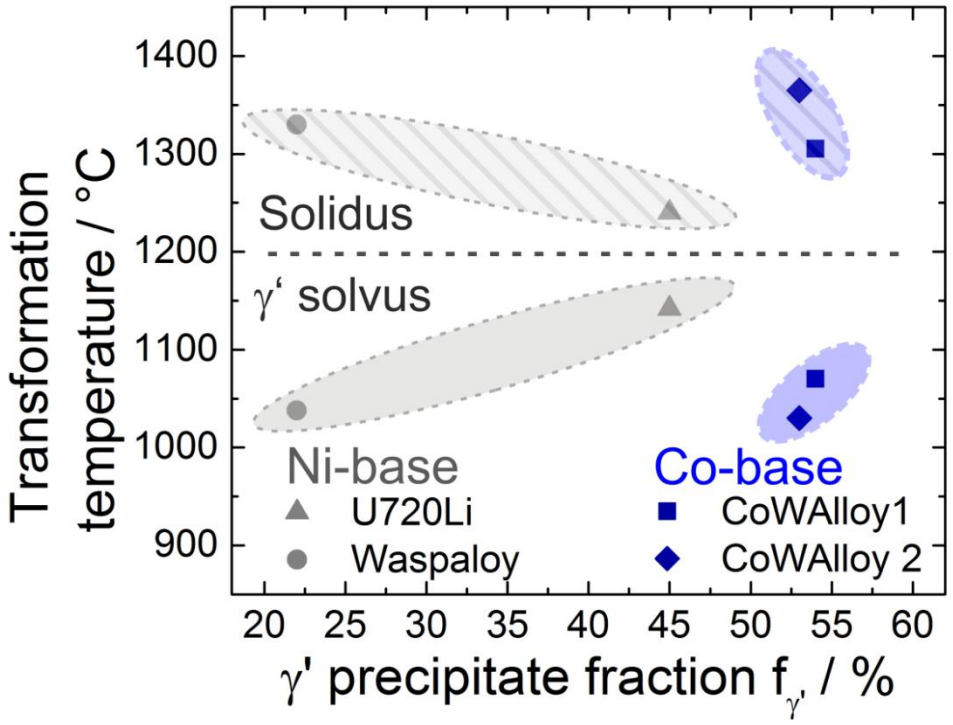


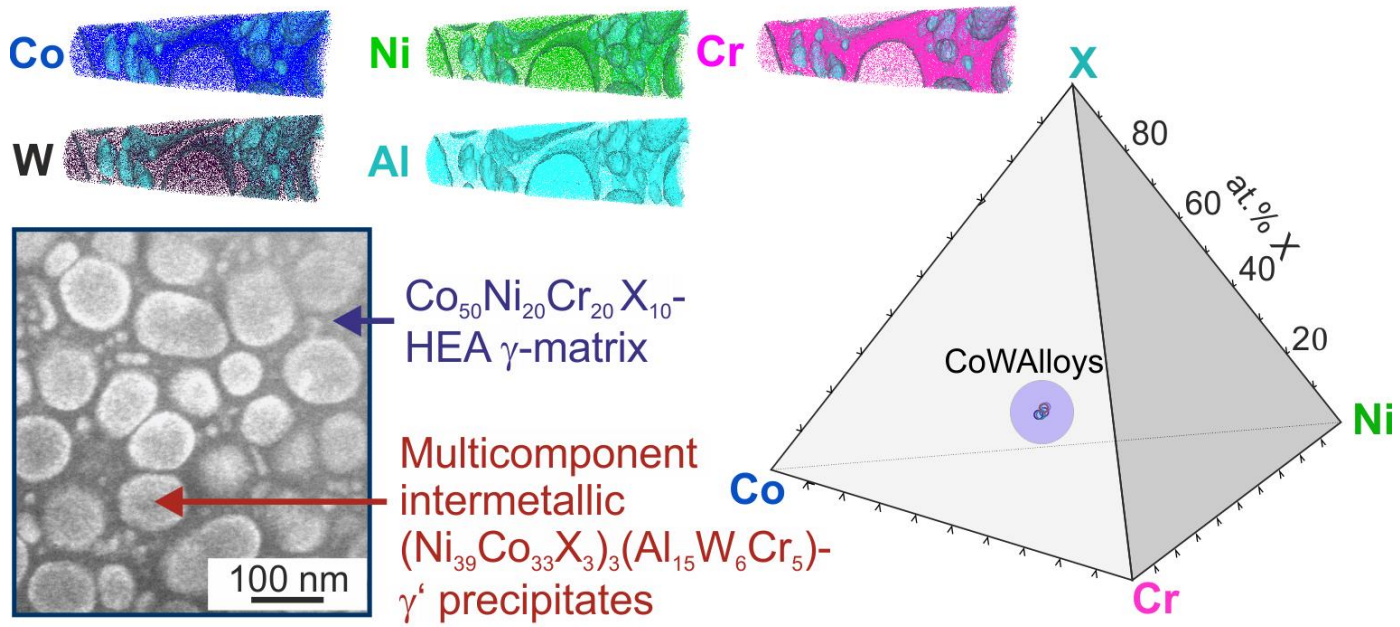

Potential new wrought Co-base superalloys

Bauer et al. (2010), Scr. Mater.

# Previously: Development of High Entropy Superalloys

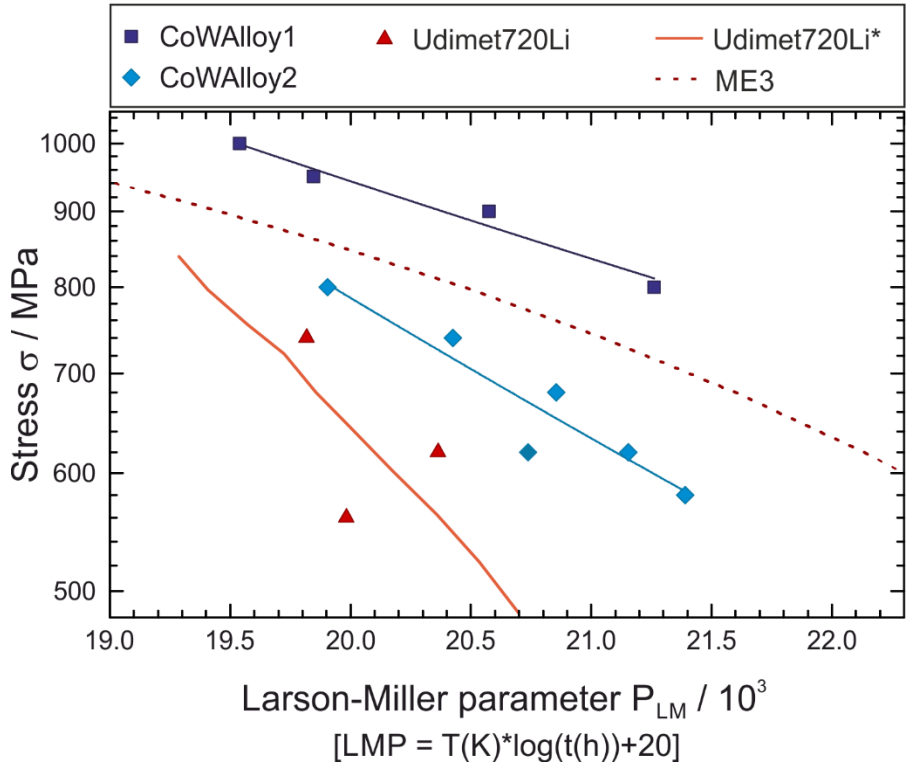
| at.% | Co | Ni | Cr | Al | W | Ti | Ta | Si | B+C+Hf+Zr |
|---|---|---|---|---|---|---|---|---|---|
| CoWAlloy 1 | 42.3 | 32.0 | 12.0 | 6.0 | 3.0 | 2.5 | 1.5 | 0.4 | <0.2 |
| CoWAlloy 2 | 40.8 | 32.0 | 12.0 | 9.0 | 5.0 | 0.3 | 0.2 | 0.4 | <0.2 |

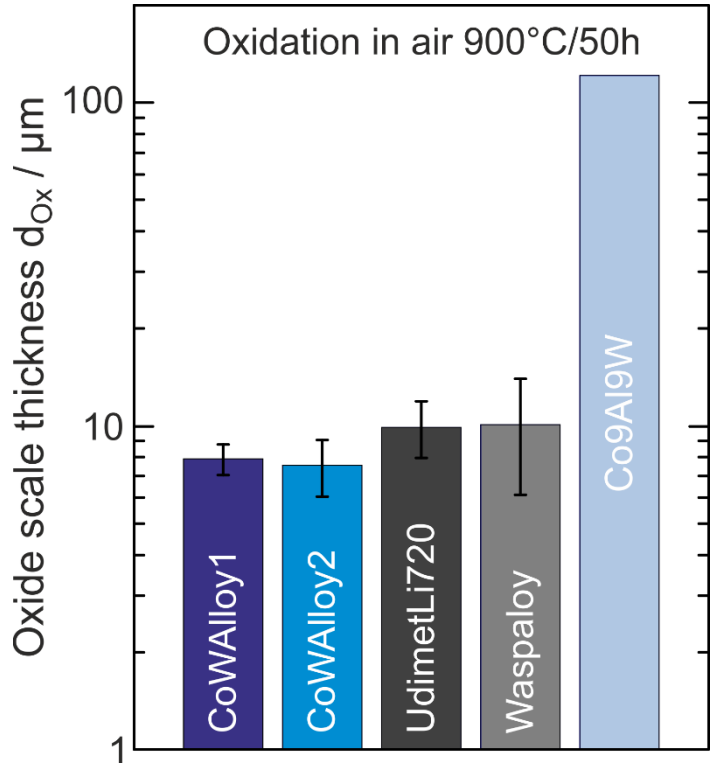


# CoWAlloys vs C&W Commercial Ni-base superalloys

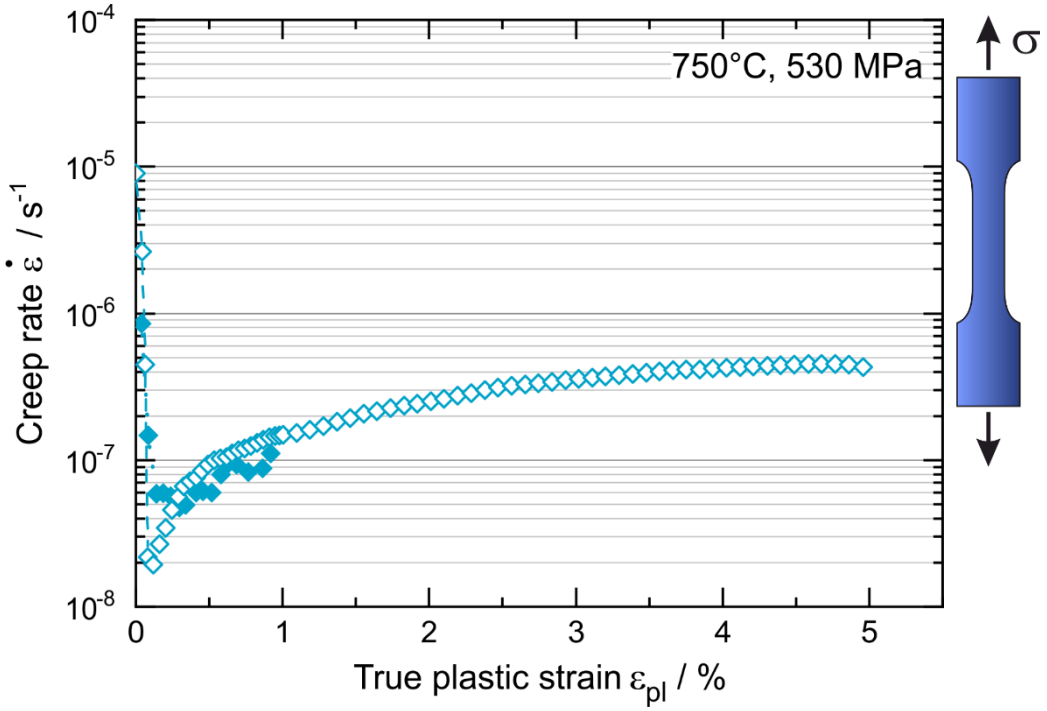
| at.% | Co | Ni | Cr | Al | W | Ti | Ta | Si | B+C+Hf+Zr |
|---|---|---|---|---|---|---|---|---|---|
| CoWAlloy 1 | 42.3 | 32.0 | 12.0 | 6.0 | 3.0 | 2.5 | 1.5 | 0.4 | <0.2 |
| CoWAlloy 2 | 40.8 | 32.0 | 12.0 | 9.0 | 5.0 | 0.3 | 0.2 | 0.4 | <0.2 |



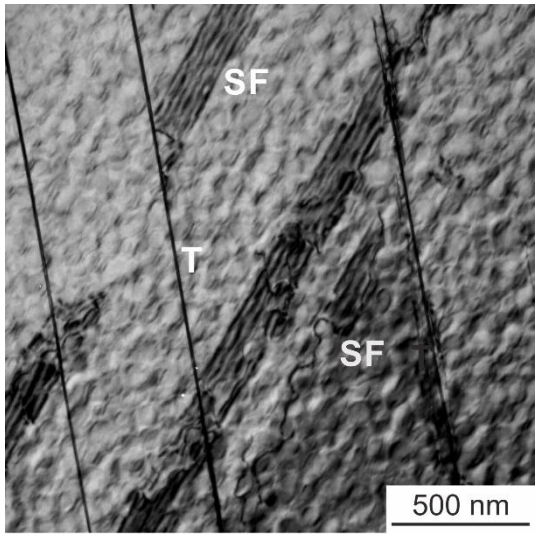



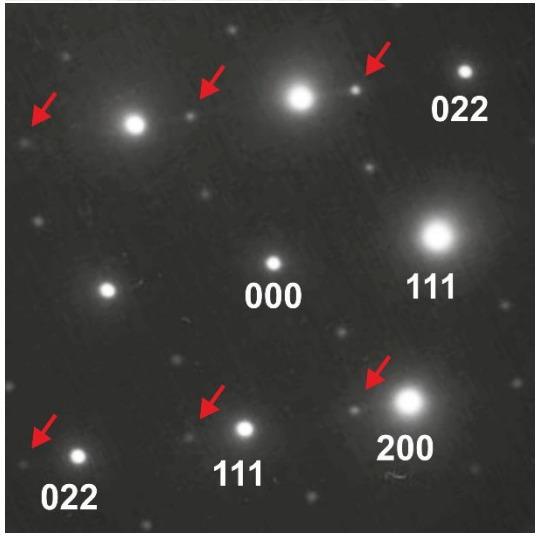

- Promising creep and oxidation properties compared to wrought polycrystalline Ni-base superalloys

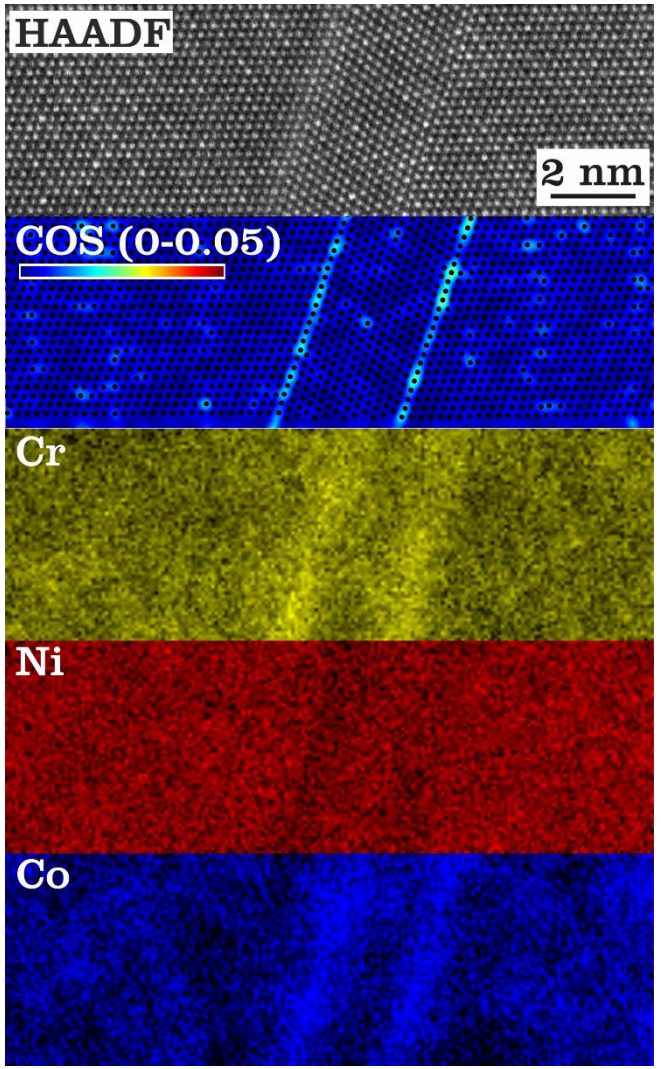
# Deformation Mechanisms of Polycrystalline High Entropy Superalloys




- Plastic deformation through stacking fault shearing and microtwinning
- Segregation-assisted shearing mechanisms

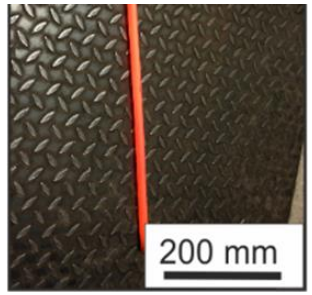


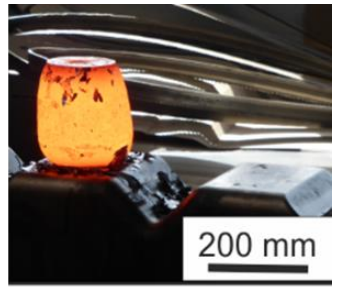



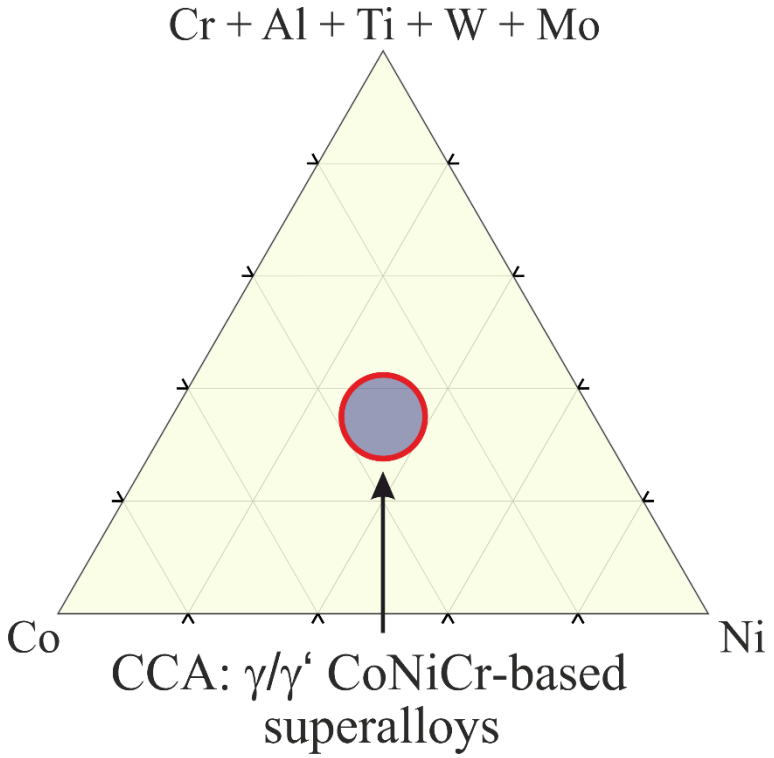



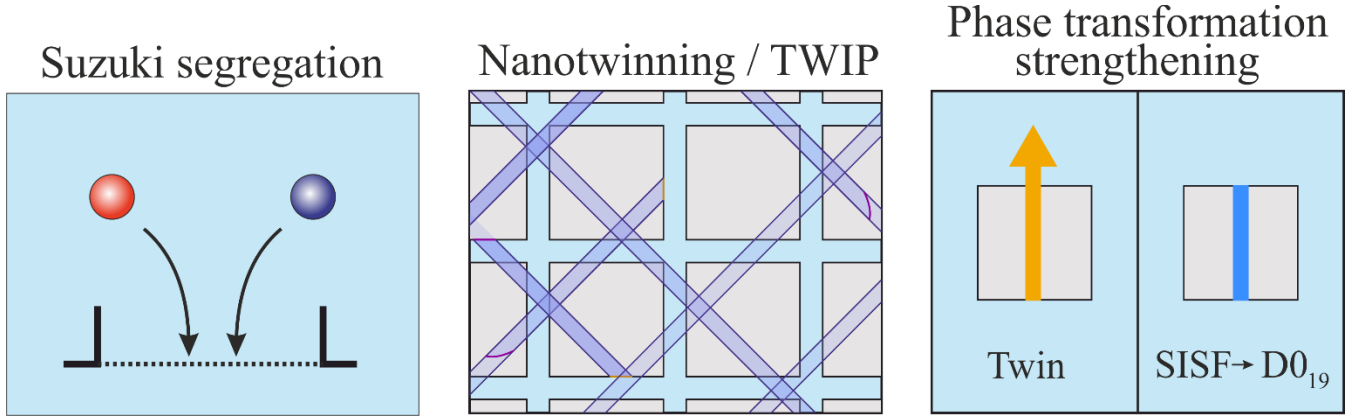
# Polycrystalline High Entropy Superalloys (PHESA)

| at.% | Co | Ni | Cr | Al | W | Mo | Ti | Ta | Si | B+C+Hf+Zr |
|---|---|---|---|---|---|---|---|---|---|---|
| PHESA-0 | 34.8 | 35.0 | 15.0 | 9.0 | | 5.0 | 0.3 | 0.2 | 0.4 | <0.2 |
| PHESA-1 | 34.8 | 35.0 | 15.0 | 7.5 | 5.0 | | 1.0 | 1.0 | 0.4 | <0.2 |
| PHESA-2 | 34.8 | 35.0 | 15.0 | 9.0 | 5.0 | | 0.3 | 0.2 | 0.4 | <0.2 |



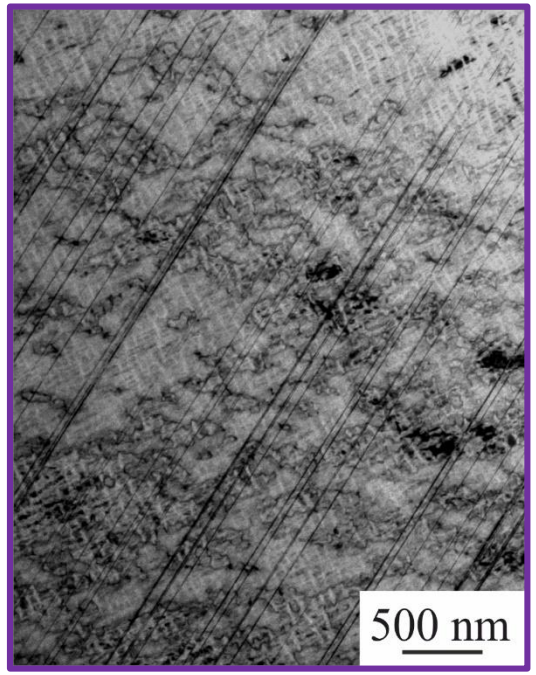



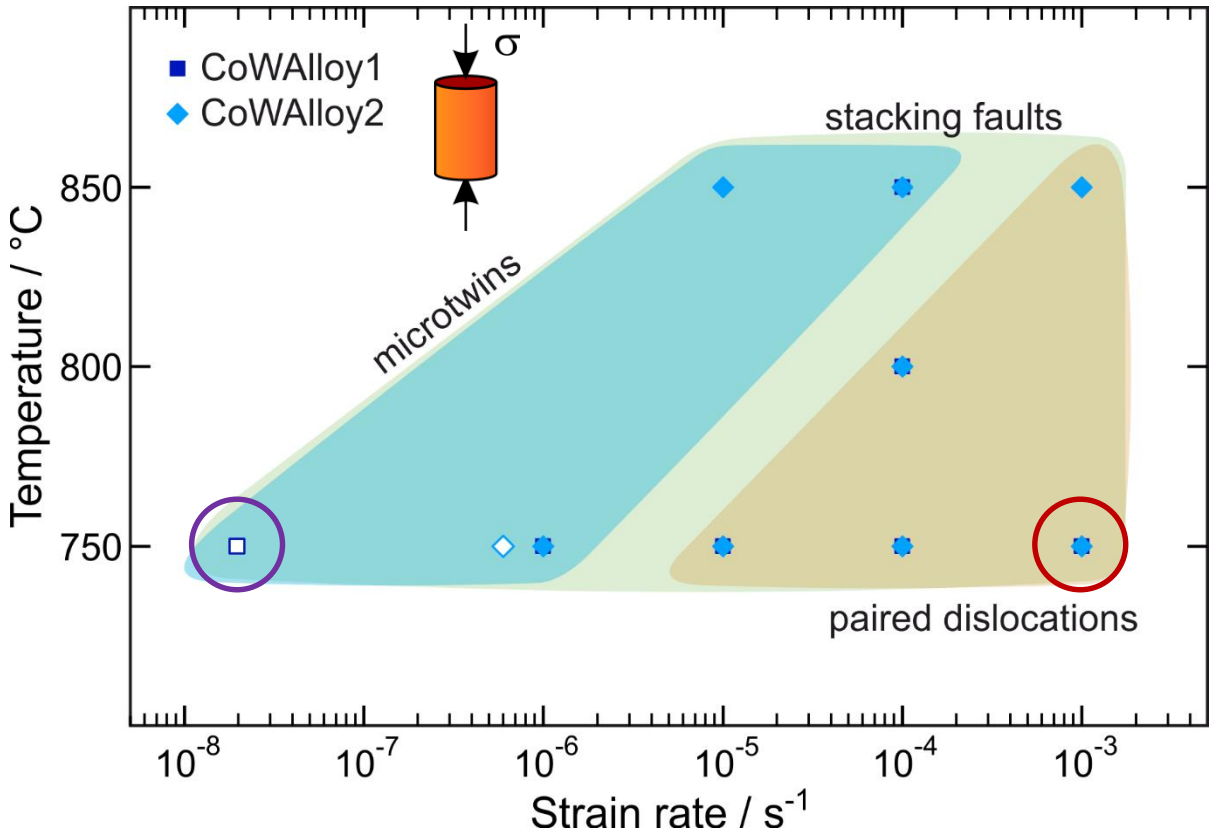

- Increase the entropy and decrease the stacking fault energy of the matrix
- Evaluate and use novel strengthening mechanisms in high entropy superalloys

# Deformation Mechanisms Mapping

**750 °C / ~ $10^{-8}$ $s^{-1}$**



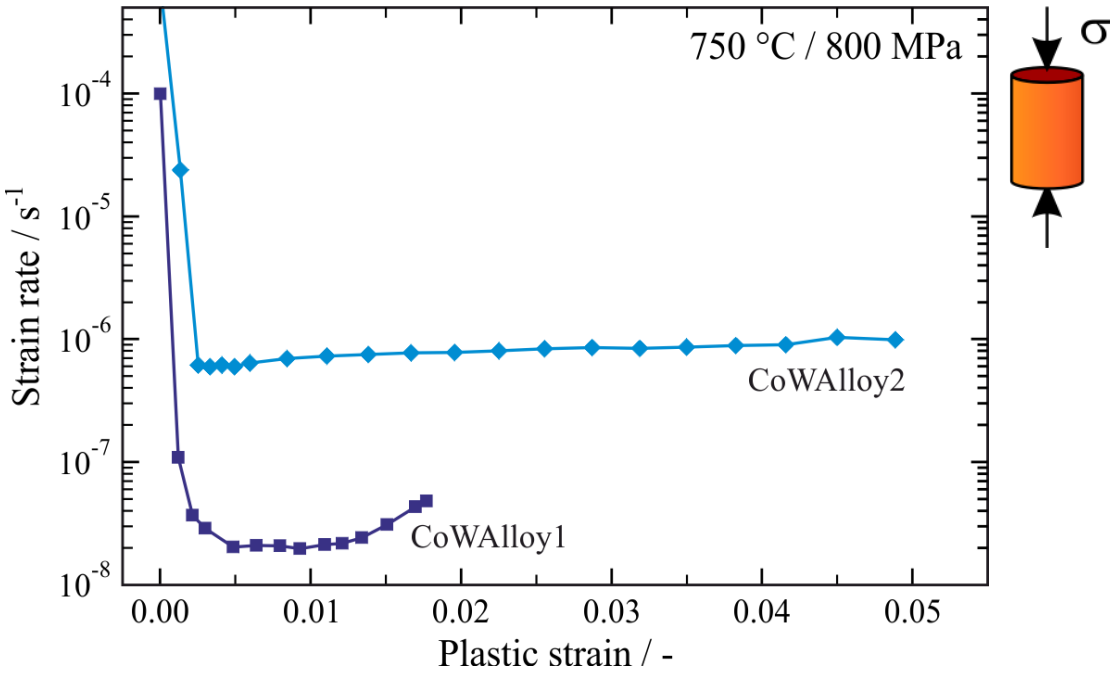

**750 °C / $10^{-3}$ $s^{-1}$**

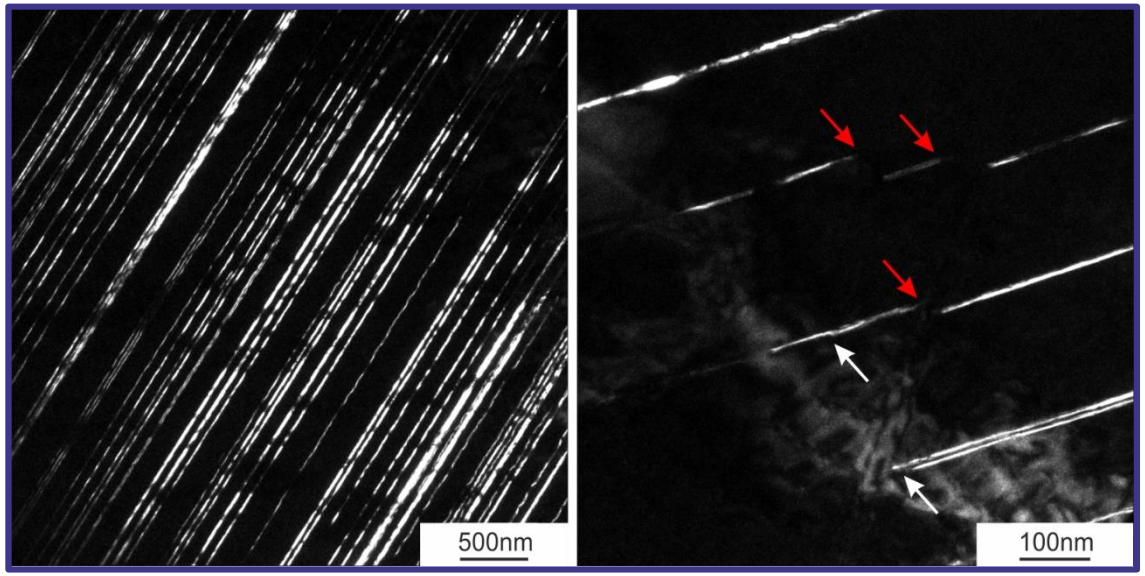




- Deformation mechanisms are strongly temperature and strain rate dependent
- Which mechanisms are occurring during tensile (creep) experiments?
- Quantification of dislocation, stacking fault and microtwin densities

# The Role of the Minor Elements Ti and Ta

| at.% | Co | Ni | Cr | Al | W | Ti | Ta | Si | B+C+Hf+Zr |
|---|---|---|---|---|---|---|---|---|---|
| CoWAlloy1 | 42.3 | 32.0 | 12.0 | **6.0** | **3.0** | **2.5** | **1.5** | 0.4 | <0.2 |
| CoWAlloy2 | 40.8 | 32.0 | 12.0 | **9.0** | **5.0** | **0.3** | **0.2** | 0.4 | <0.2 |

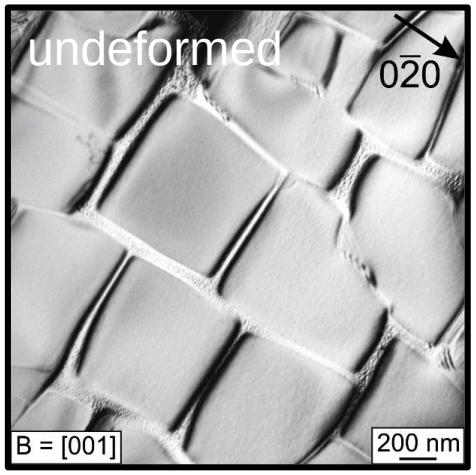


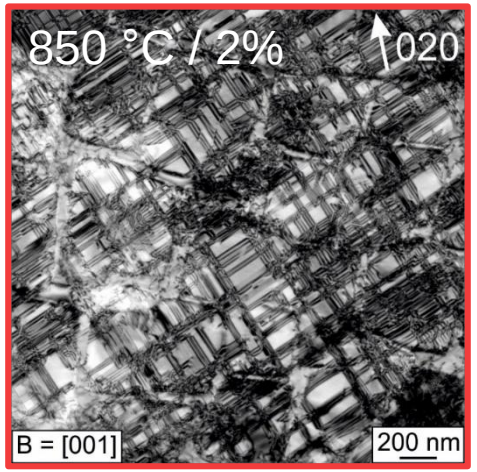



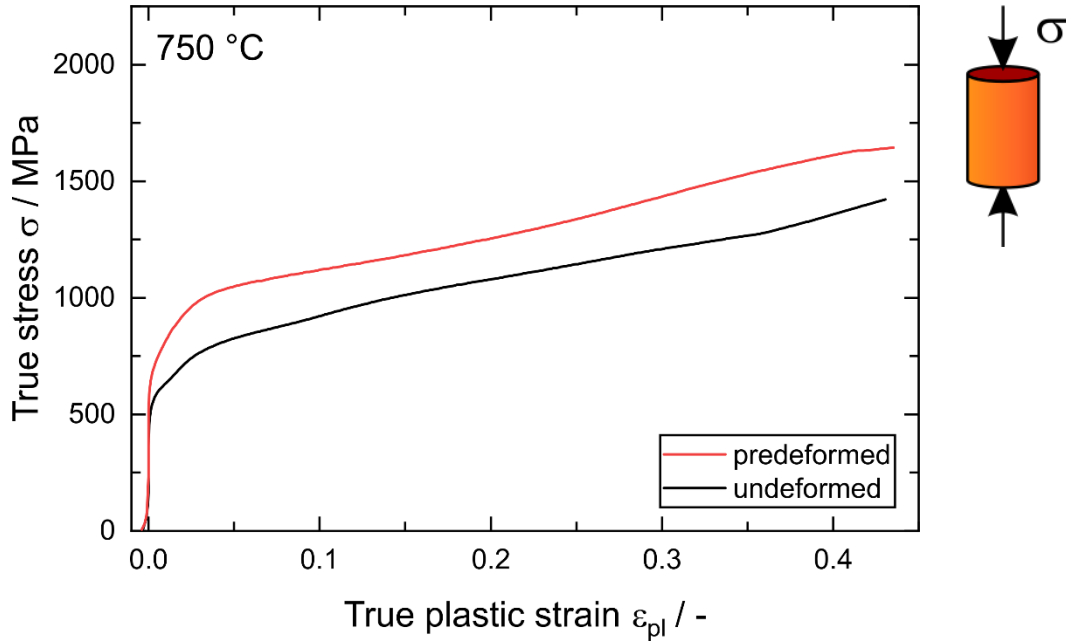

- Higher density of thinner nanotwins in CoWAlloy1
- Different segregation behaviour?
- Phase transformation strengthening?

# Strengthening Effect of Nanotwinning

| at.% | Co | Ni | Cr | Al | W | Ti | Ta | Si | Hf |
|---|---|---|---|---|---|---|---|---|---|
| ERBOCo-4 | 43.2 | 32.0 | 6.0 | 8.0 | 5.7 | 3.8 | 1.8 | 0.4 | 0.1 |




- Can we use a similar effect in polycrystalline high entropy superalloys?
- Correlation between nanotwin thickness and effective strengthening contribution?
- How significantly does this predeformation influences the ductility?

# Suzuki Segregation in High Entropy Superalloys

| at.% | Co | Ni | Cr | Al | W | Mo | Ti | Ta | Si | B+C+Hf+Zr |
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| PHESA-0 | 34.8 | 35.0 | 15.0 | 9.0 | | 5.0 | 0.3 | 0.2 | 0.4 | <0.2 |
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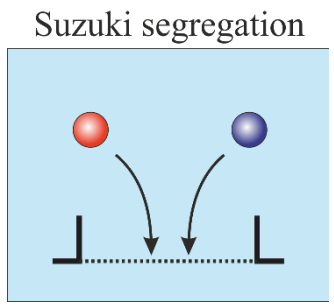
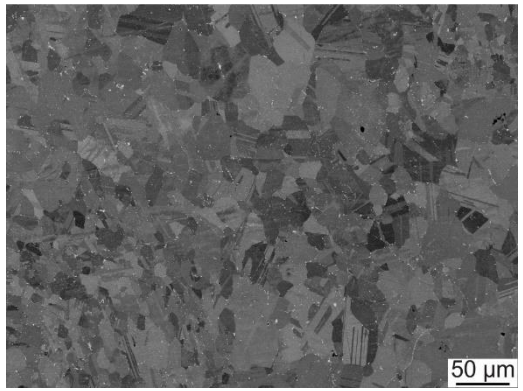
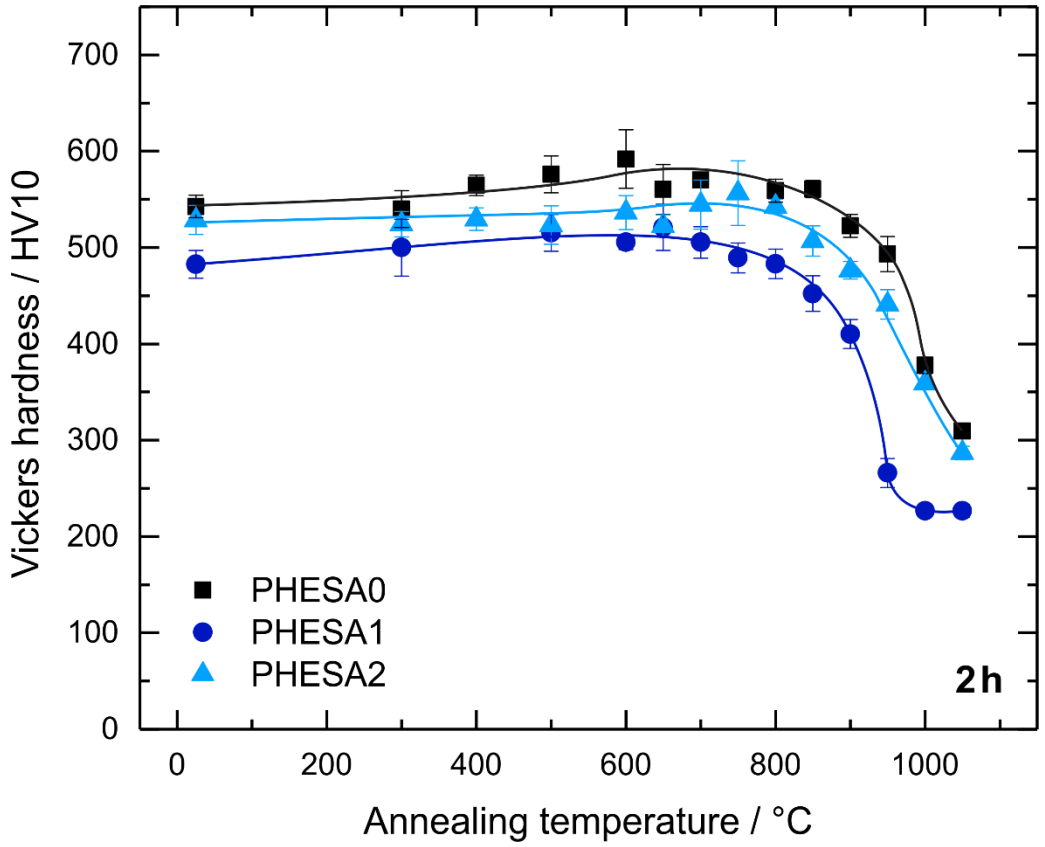



**PHESA 2**




- Cold rolling (50 %)
- Annealing for 2 h




- Increase in hardness due to Suzuki segregation?
- Formation of intermetallic phases?
- Investigation through correlative microscopy FIB-TEM-APT

# Suzuki Segregation in High Entropy Superalloys

| at.% | Co | Ni | Cr | Al | W | Mo | Ti | Ta | Si | B+C+Hf+Zr |
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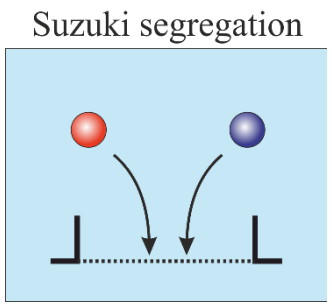
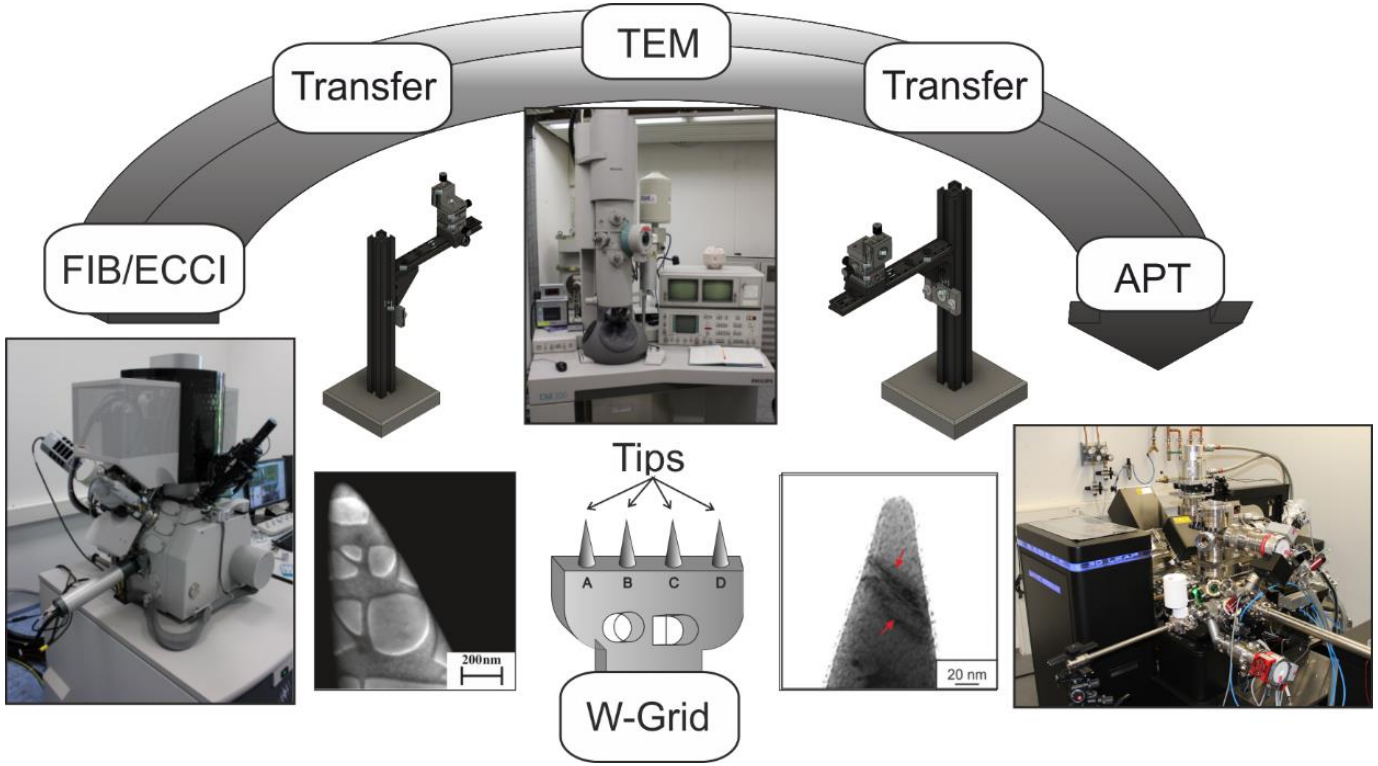
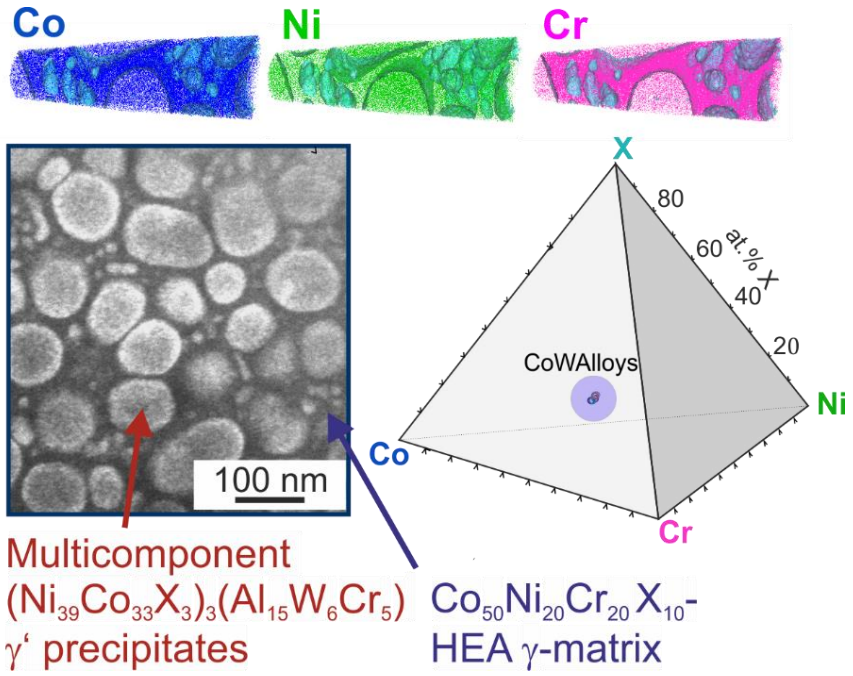


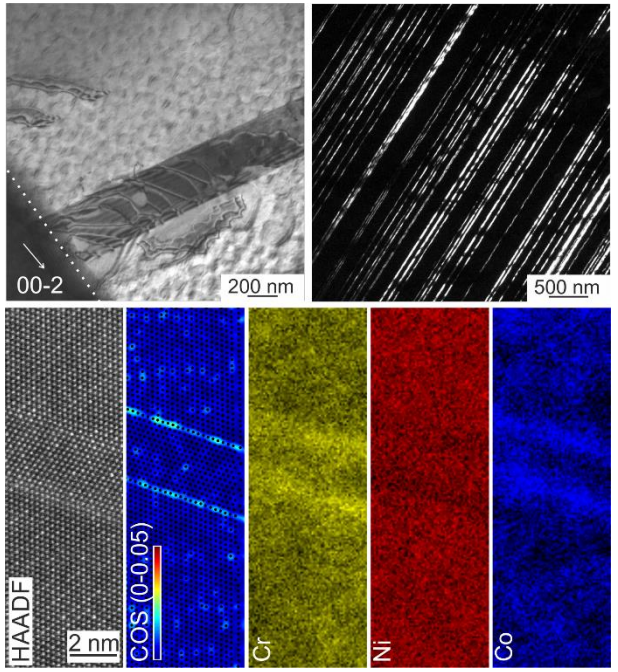

- Increase in hardness due to Suzuki segregation?
- Formation of intermetallic phases?
- Investigation through correlative microscopy FIB-TEM-APT

# Polycrystalline High Entropy Superalloys (PHESA)

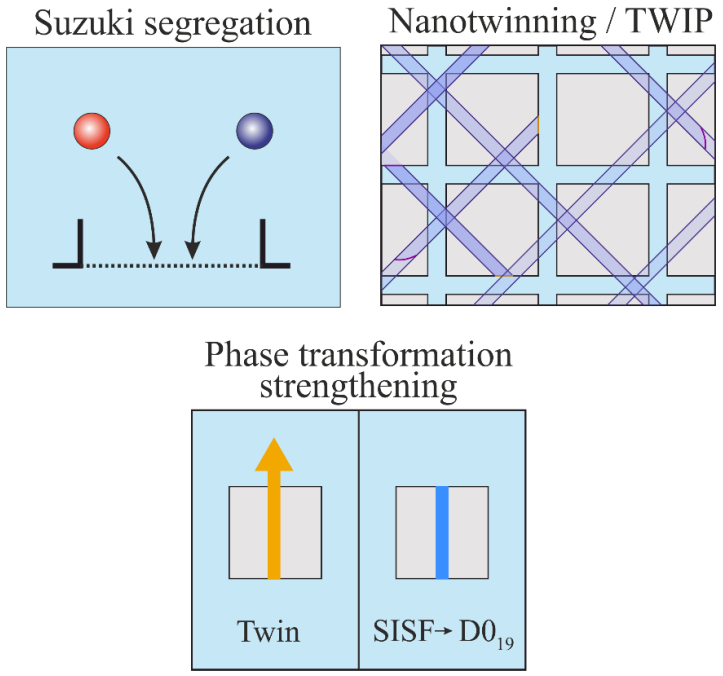
## Previously: Investigations on High Entropy Superalloys




## Now: Rationalization of deformation mechanisms




## Now: Additional strengthening mechanisms




- Investigation and rationalization of the deformation mechanisms during high temperature tensile deformation
- Evaluation and combination of unexplored strengthening mechanism in CCAs/High Entropy Superalloys
- We are looking forward to collaborating with you! ☺