Particle-strengthened Compositionally Complex Alloys
Interlinking powder synthesis, additive manufacturing, microstructure evolution and deformation mechanisms (PaCCman)

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Dislocation Deformation Mechanisms

Literature:
Mechanical data linked to TEM dislocation studies

Large scatter of values in the literature
One reason: nm-sized precipitates are often overlooked and CCA are interpreted as HEA

**Particle-strengthening** is a promising mechanism for application of **high-strength CCA at elevated temperatures**

⇒ **Fundamental understanding** of
  - dislocation-based deformation mechanisms
  - dislocation-particle interaction
  - at elevated temperatures

in concentrated solutions is still in its infancy.
Investigated CCA systems and AM

CrFeCoNi
CrFeCoNi
AlCrFeCoNi
AlCrMnFeCoNi

A1
A2
B2 matrix (multiphase alloy)

+ Nitrogen

CrN (?)
in A1 matrix

B2

in A1 matrix

CrN (?)
in A1 matrix

AlN (?)
in A2 matrix

4 matrix/particle combinations targeted

Deformation Mechanism

Requirements:
- Flexibility in compositions
- Chemically homogeneous
- Supersaturated solid solution
- nm-sized, well-dispersed precipitates
- sufficient sample sizes for mech. testing

Selective Laser Melting (SLM) is a process enabling rapid alloy prototyping
process showing rapid solidification
near net-shape process

But: Control over powder quality essential!
- Powder chemistry
- CCA powder microstructure
- Flowability

Selective Laser Melting (SLM) is a process enabling rapid alloy prototyping
**Synthesis**

- Desired **optimal flowability** via Anti-Satellite atomization

**Anti-Adhesion Additives**

- Enhanced **powder processing** via additive SiO$_2$ nanopowder

**Deformation Mechanism**

**Desired optimal flowability** via Anti-Satellite atomization

**Effect of Anti-Satellite System**

- Satellites decrease flowability

**Particle Size** $x_p$ in $\mu$m

**Roughness radius** $R$ in nm

**Van-der-Waals Force** $F_{\text{vdW}}$ in $\mu$N

**Van-der-Waals sticking**

**Target for optimum flowability**

**Satellite locking regime**

**Particle Size** $x_p$ in $\mu$m

**Effect of Anti-Satellite System**

- Anti-Sat.-System
- no Anti-Sat.-System

**Circularity** $C$

- Anti-Sat.-System
- no Anti-Sat.-System

- **Desired optimal flowability**
- **Bad flowability**
- **Good flowability**

**Additive Manufacturing**

**Desired optimal flowability**

**Adjacent figure:**

- Satellite particles
- Van-der-Waals Force $F_{\text{vdW}}$ in $\mu$N
- Particle size $D = 0.4$ nm
- van-der-Waals sticking
- satellite locking regime

**Powder Technology**

**Effect of Anti-Satellite System**

- **Satellites decrease flowability**

**Parameter:**

- Particle Size $x_p$ in $\mu$m
- Roughness radius $R$ in nm
- Van-der-Waals Force $F_{\text{vdW}}$ in $\mu$N
- Circularity $C$
Toolbox and preliminary work

EDS – Scanning TEM – Z-contrast

AlCrFeCoNiCu0.5

B2

bcc (A2)

N. Peters, MPIE unpublished

SLM

adjusted process parameters

In-situ TEM

5 nm

100 nm

S. Lee, SKKU unpublished

APT of nitrided Fe-Al-Cr

50% Al
13% Cr

100 nm

Deformation Mechanism

HT mech. testing

Deformation Mechanism

Characterization

Additive Manufacturing

SLM

10 mm

flow simulation

particle tracking simulation

Powder Technology

powder plant

atomization

hi-speed image

flow simulation

characterization

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Summary and collaborations

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WP1 • Develop powder synthesis of particle-strengthened CCA
⇒ Ensure composition-independent powder flowability and hence processability

WP2 • Establish Selective Laser Melting as component production process for particle-strengthened CCA
⇒ Flexible and fast production of homogenous cm-sized parts

WP3 • Fundamental understanding of dislocation-based plasticity in CCA matrix and particle-strengthened CCA
⇒ Tailor mechanical properties at variable temperatures

Thank you for your attention!