Anomalous strength behavior by dislocation locking

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ESPark Research Group
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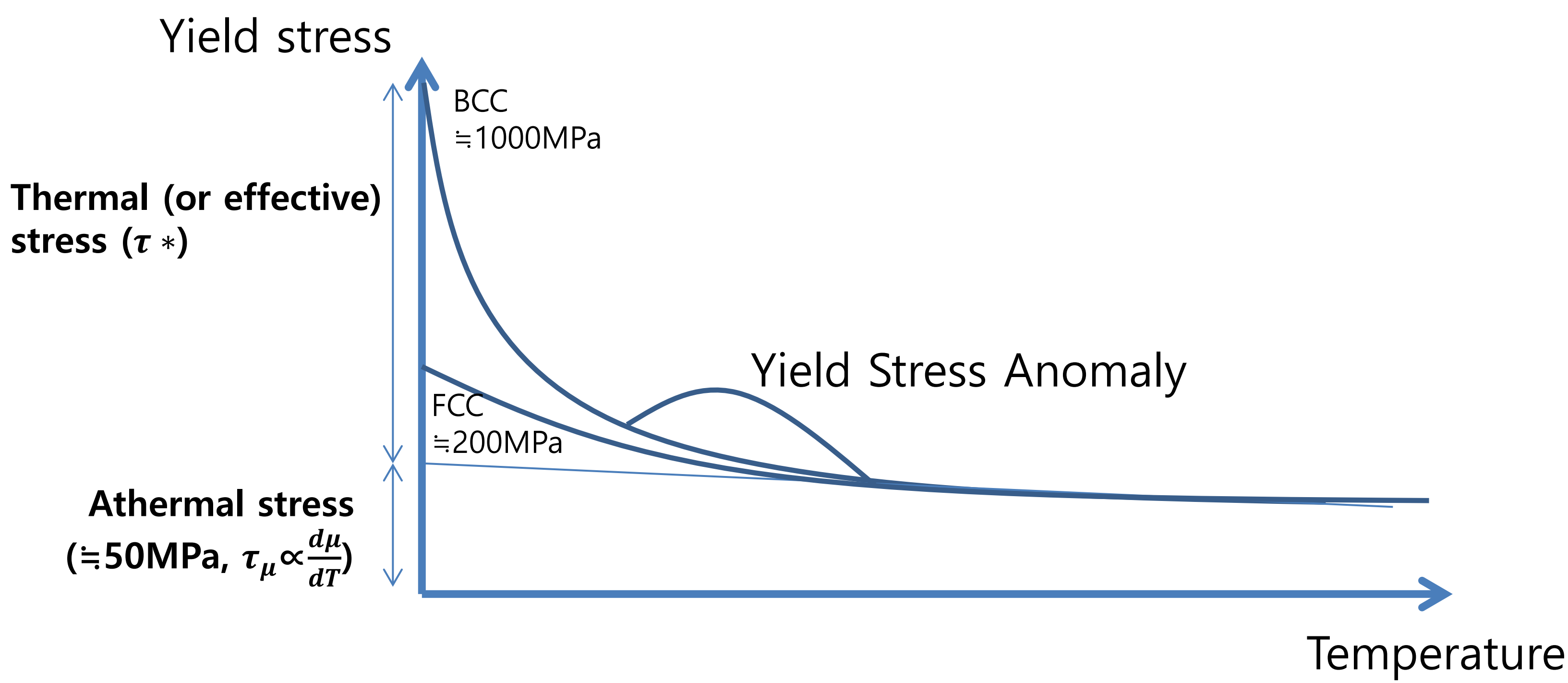
Introduction

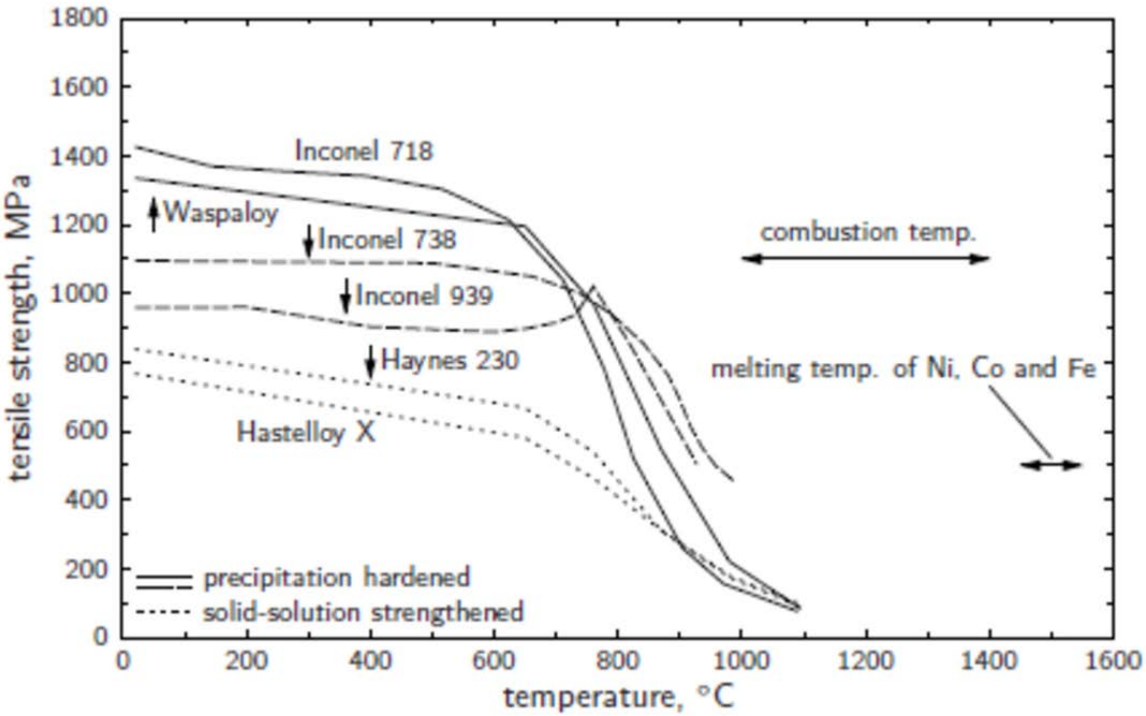
- General yield stress behavior of pure metal depending on temperature



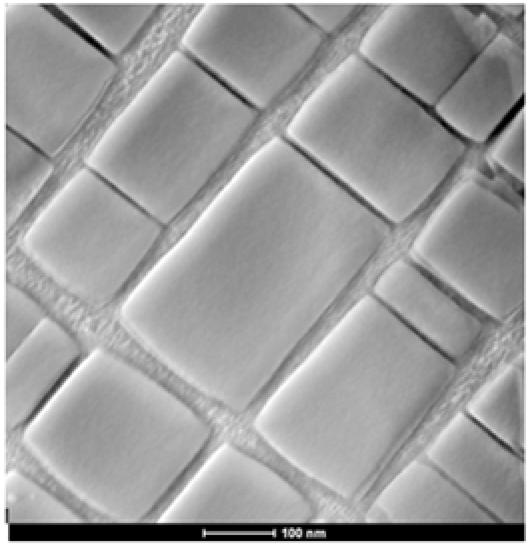
- $\tau = \tau * + \tau_\mu$
- Yield stress anomaly is occurred by two mechanism;
  1) one is cross slip related mechanism
  2) and the other is diffusion related mechanism.

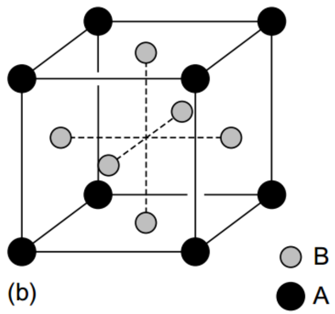
Ni-based Superalloy

R. Eriksson, PhD thesis, 2011



Ordered structure precipitation

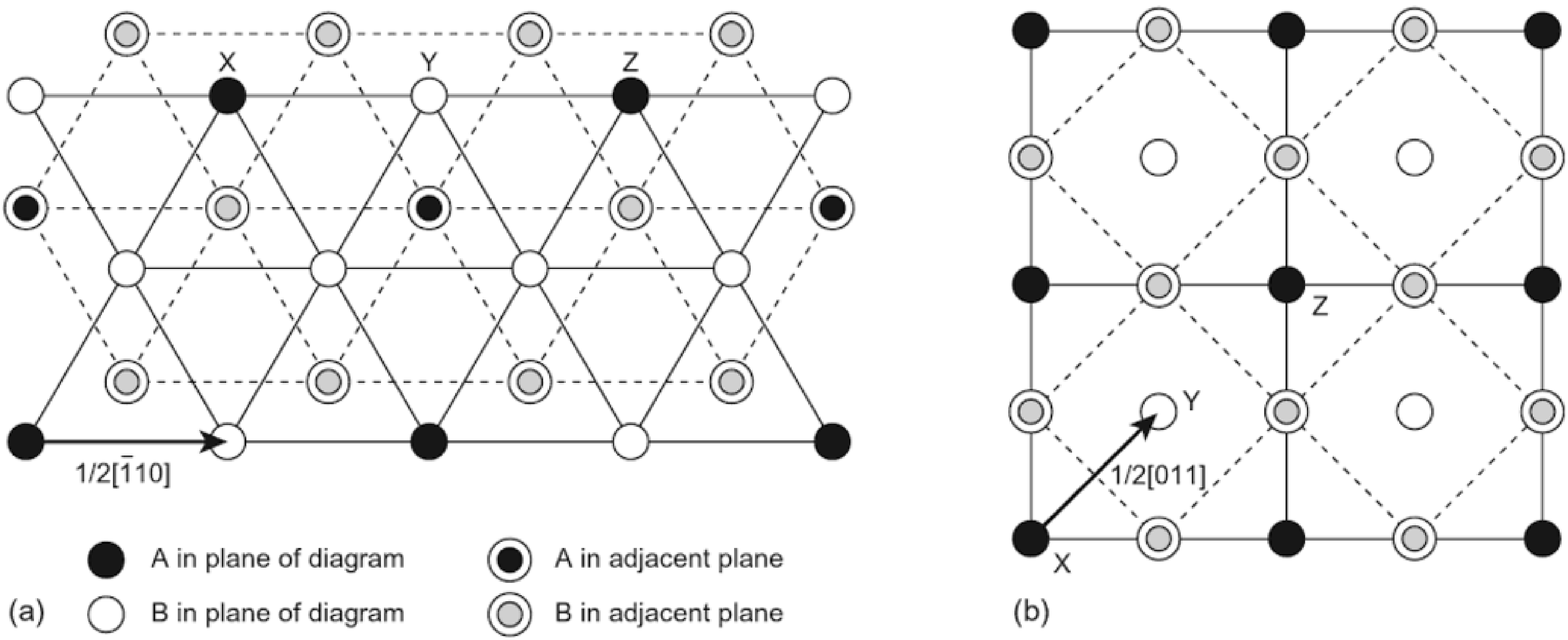




- Ni-based superalloy shows constant yield stress until 800℃
- FCC matrix + $L1_2$ precipitation
- To improve engine efficiency, operating temperature must be increased

Antiphase boundary(APB) in $L1_2$ structure

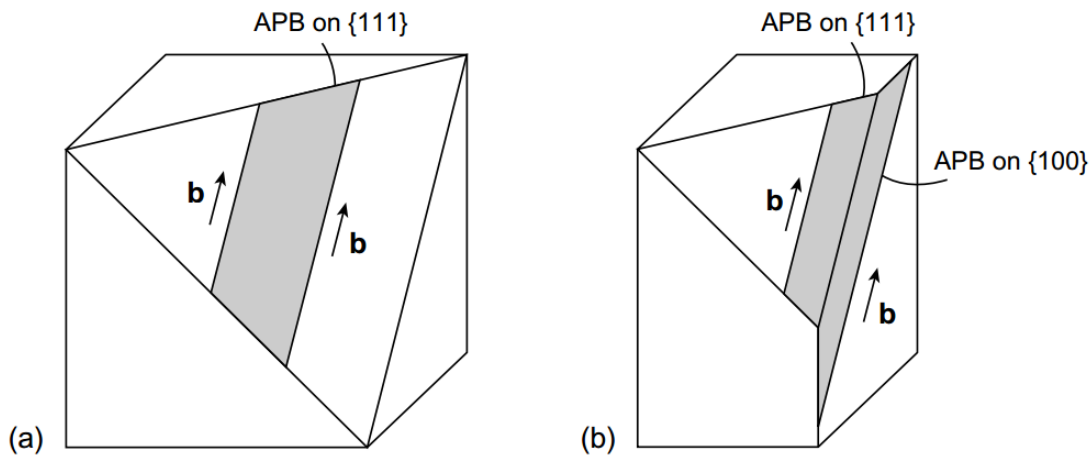
D. Hull, D. J. Bacon, Introduction to Dislocation, 2011



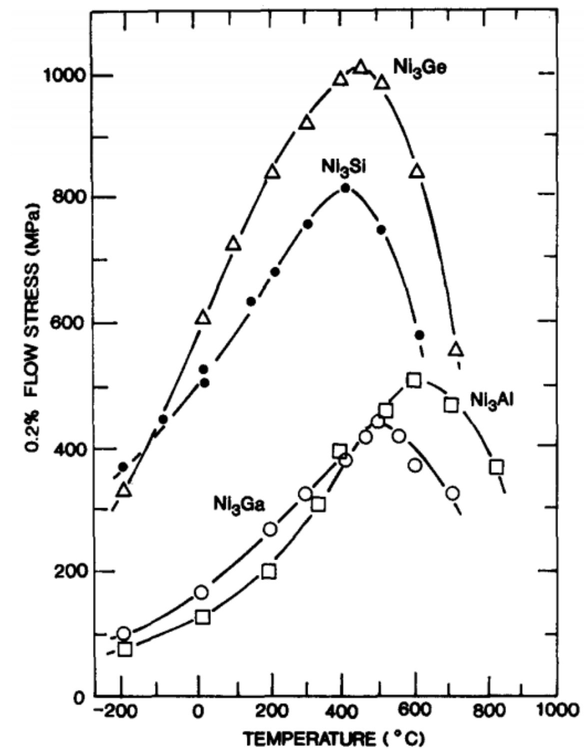
- For $L1_2$ structure, ½<110> dislocation is Burgers vector like FCC structure
- {111} plane has a larger APB energy than {100} plane; second-nearest order
- Thus, the perfect dislocation consists of two ½<110> superpartial dislocations joined by an APB

Antiphase boundary(APB) in $L1_2$ structure

D. Hull, D. J. Bacon, Introduction to Dislocation, 2011

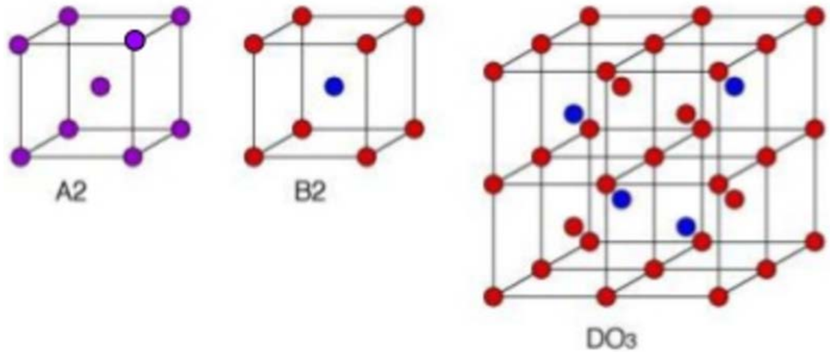


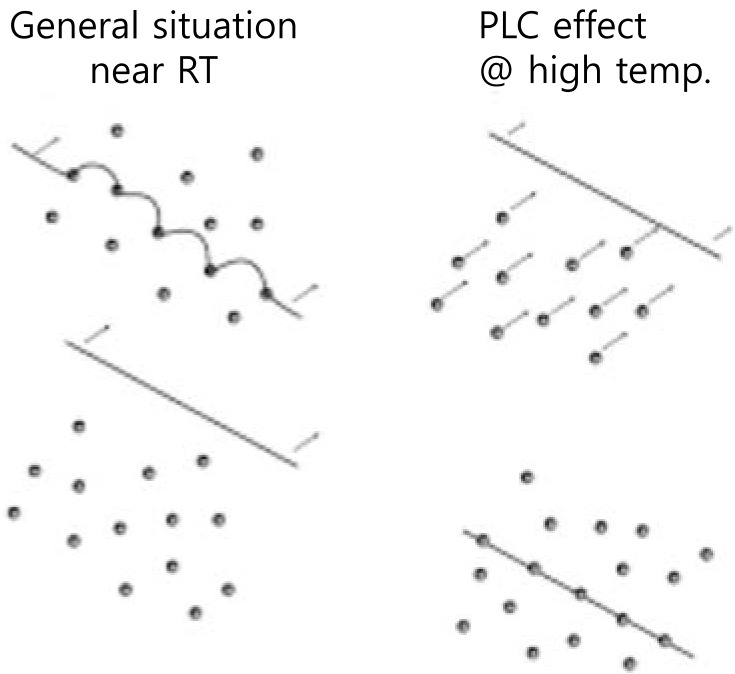
Yamaguchi, Progress in Materials Science, 1990



- Perfect screw dislocation will be dissociated two partial dislocation connected by APB.
- If one of the superpartials is not dissociated, it can glide on a {100} plane.
- When cross slip onto {100} planes occurs, glide of the dislocation on {111} plane is restricted.
- When temperature increases, cross slip onto {100} planes also increases.
- This mechanism is known as Kear-Wilsdorf lock.
- Ni_3Al, Ni_3Ga, Ni_3Si, Co_3Ti …

Diffusion controlled dislocation locking





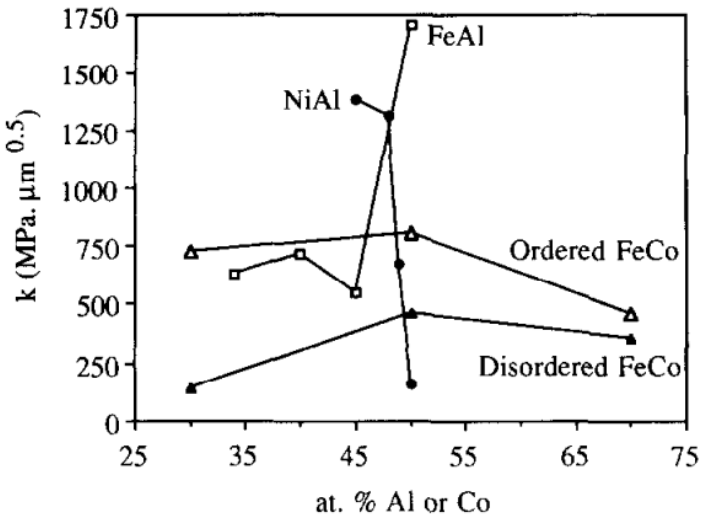
- The friction stress on mobile dislocations increases with increasing temperature
- The friction stress increases for decreasing dislocation velocity, because there is more time for diffusion on slow dislocations
(Negative strain rate sensitivity)

Diffusion controlled dislocation locking

- Activation energies for creep

Alloy	Structure	ΔH (kJ mol^{-1})	$\Delta H/RT_m$	n
CuZn	Ordered	160	17	3.5
CuZn	Disordered	97	10	3.5
FeCo–V	Ordered	689	47	4.6
FeCo–V	Disordered	395	27	4.6

- Fracture toughness

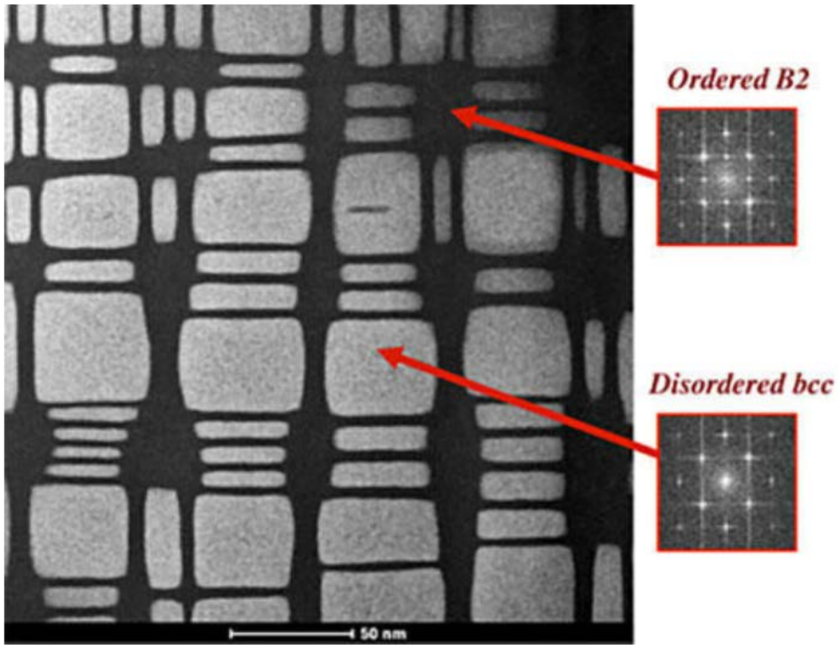


I. Baker, MSE: A, 1995

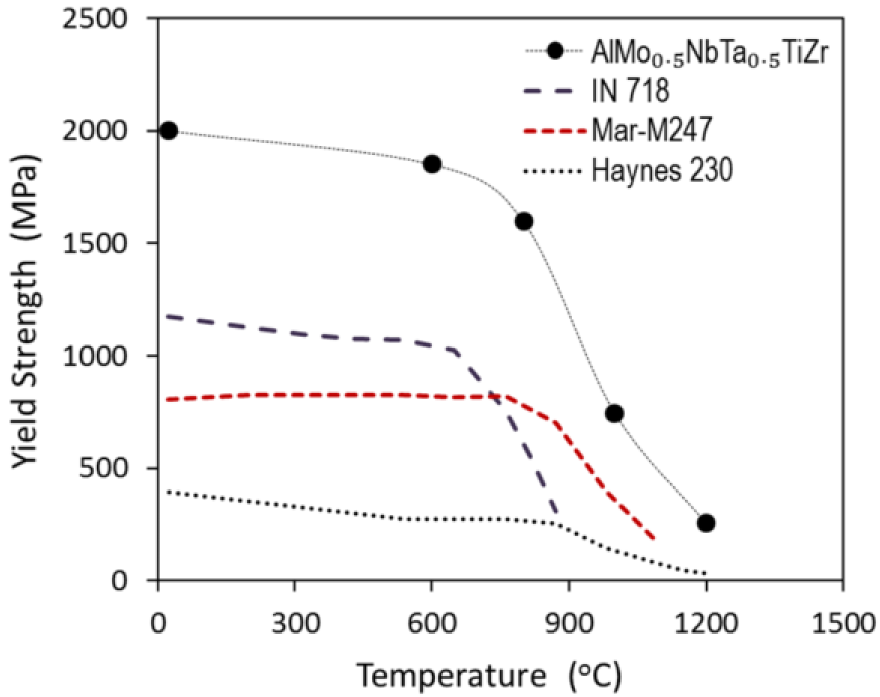
- Diffusion of solute atoms onto dislocation cores can be dislocation locking mechanism
- Relaxation of the atomic structure of the APB ribbons
- Change of APB planes by climb
- Creep and Fracture toughness can be improved by ordering phase

High Entropy Superalloy

$AlMo_{0.5}NbTa_{0.5}TiZr$



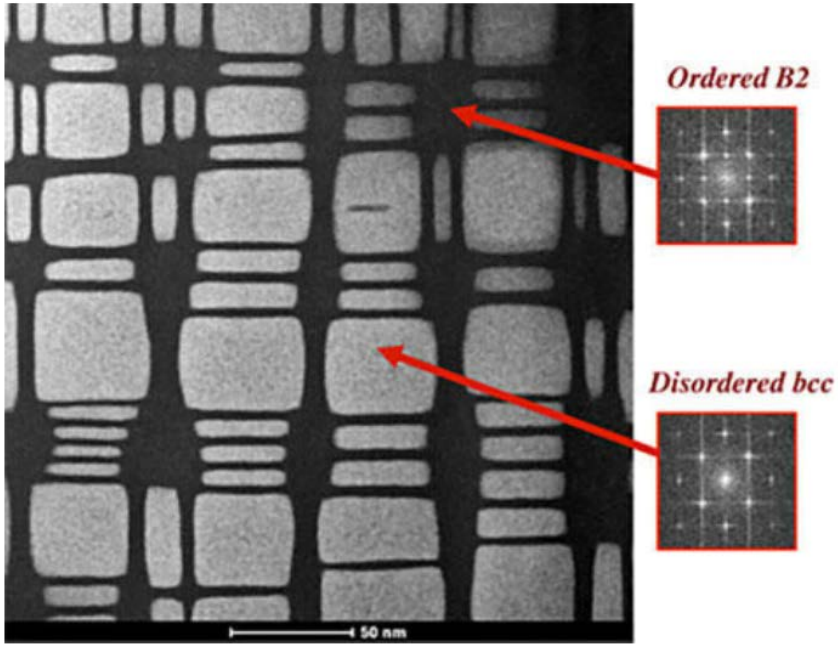
O. N. Senkov, Entropy, 2016

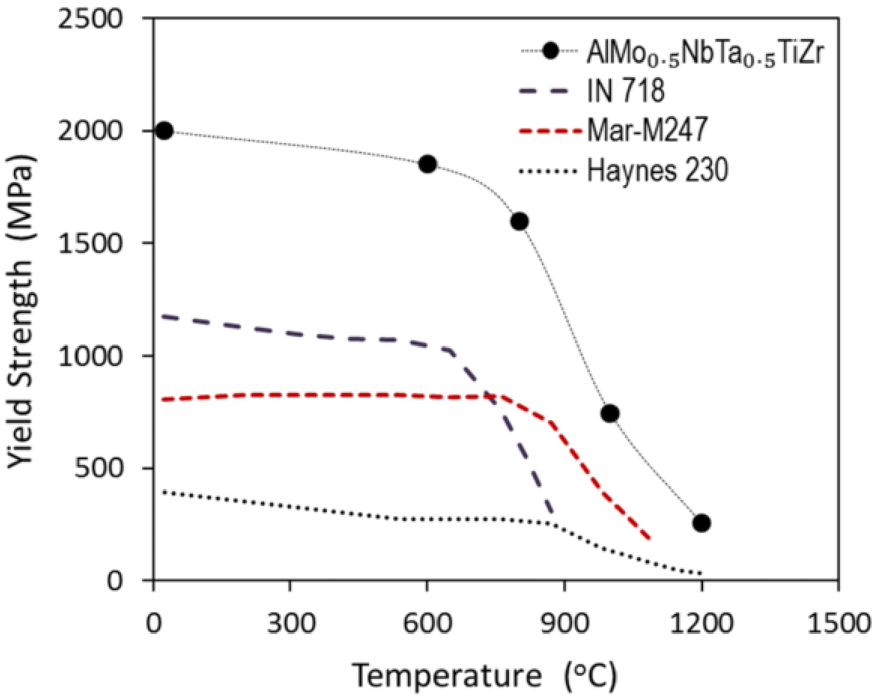


Region	Al	Mo	Nb	Ta	Ti	Zr
Overall APT reconstruction [1]	17.6	10.1	21.0	10.6	20.9	19.6
Cuboidal precipitates [2]	3.7	15.6	31.8	21.9	17.2	9.5
Thin matrix channels between precipitates [2]	12.1	11.7	25.8	15.2	19.2	15.8
Large long matrix channel [2]	25.9	5.5	14.2	4.0	24.1	25.9
Large gap in cuboidal row [2]	26.1	7.7	13.7	3.7	24.1	24.1

[1] Statistical error < 0.01 at.%; [2] Statistical error < 0.1 at.%.

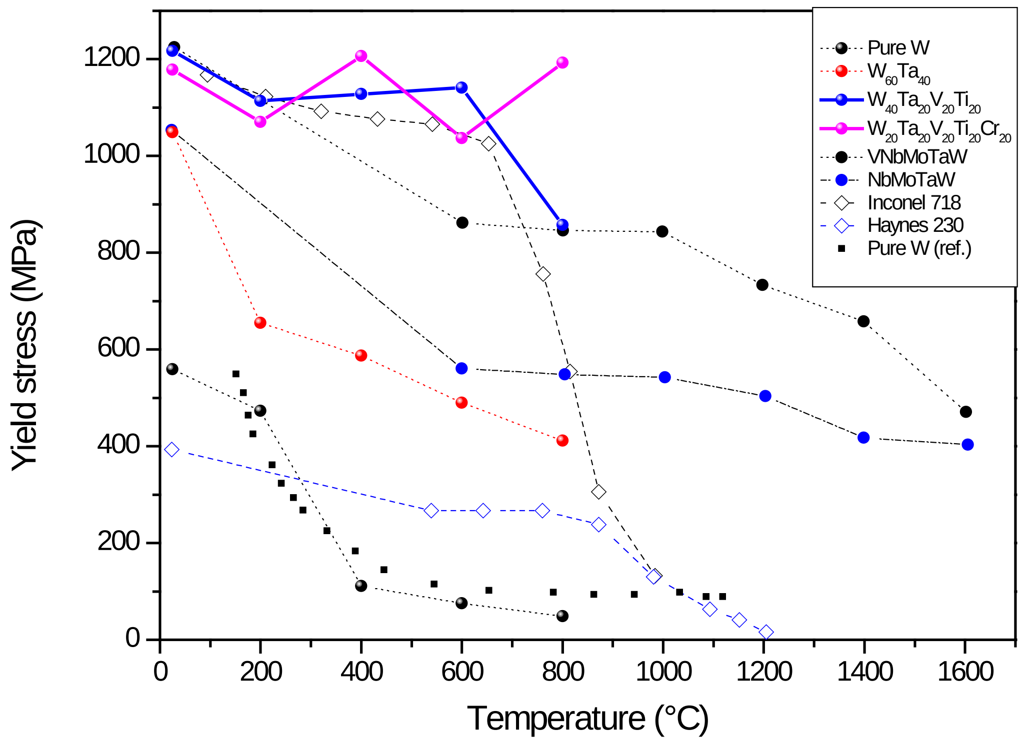
$AlMo_{0.5}NbTa_{0.5}TiZr$

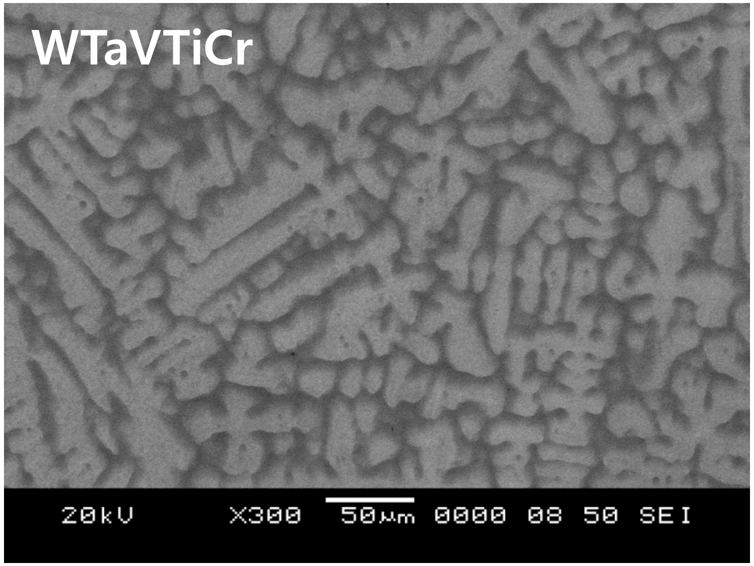




- Ordered B2 matrix + Disordered bcc precipitation
- A high volume fraction of the heterophase boundaries between the phases impedes the deformation flow
- Dynamic strain aging affects high temperature yield strength

Conclusion





- High temperature materials must have precipitations which inducing yield stress anomaly phenomena
- Ni-based superalloys: cross slip controlled dislocation locking mechanism
- BCC or B2 phase: Diffusion controlled dislocation locking mechanism
- In refractory alloys, high temperature stable phase must be investigated