Medium Mn TRIP-assisted steels

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   - Effect of aluminum on mechanical performance

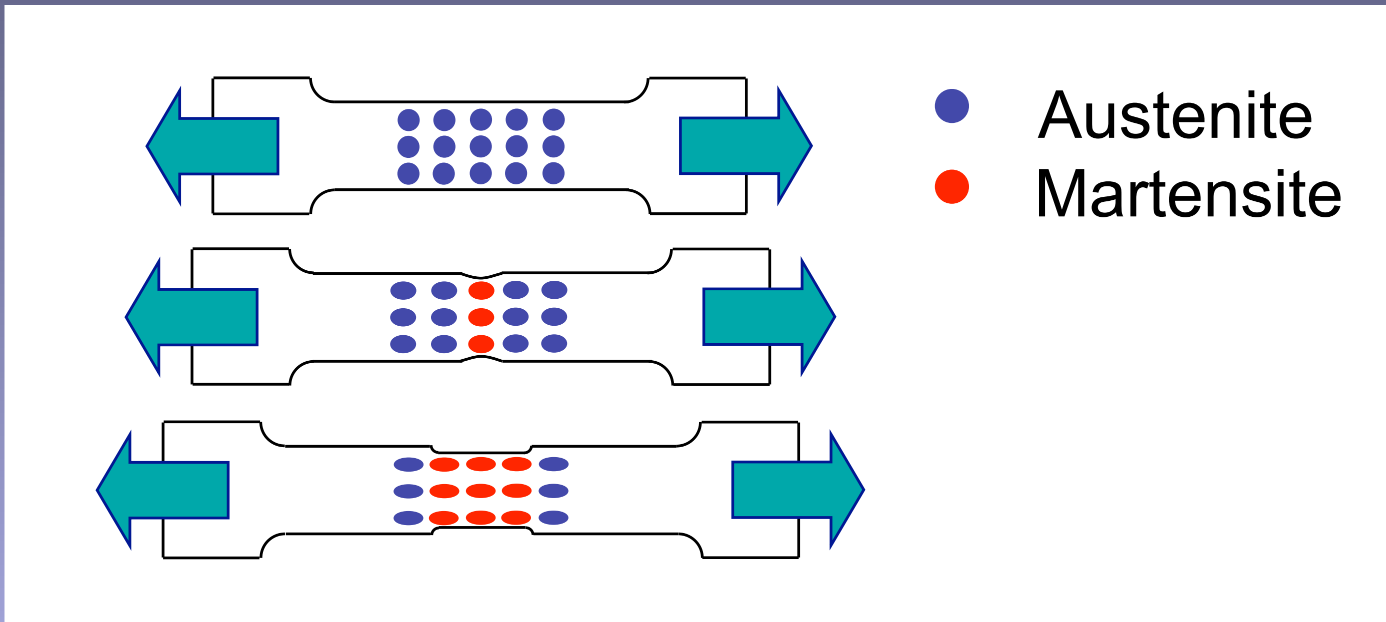
3. C and Mn balance in Al-reduced Mn TRIP-assisted steels
   - Integration of grain size effect on kinetics of martensite transformation

4. Summary

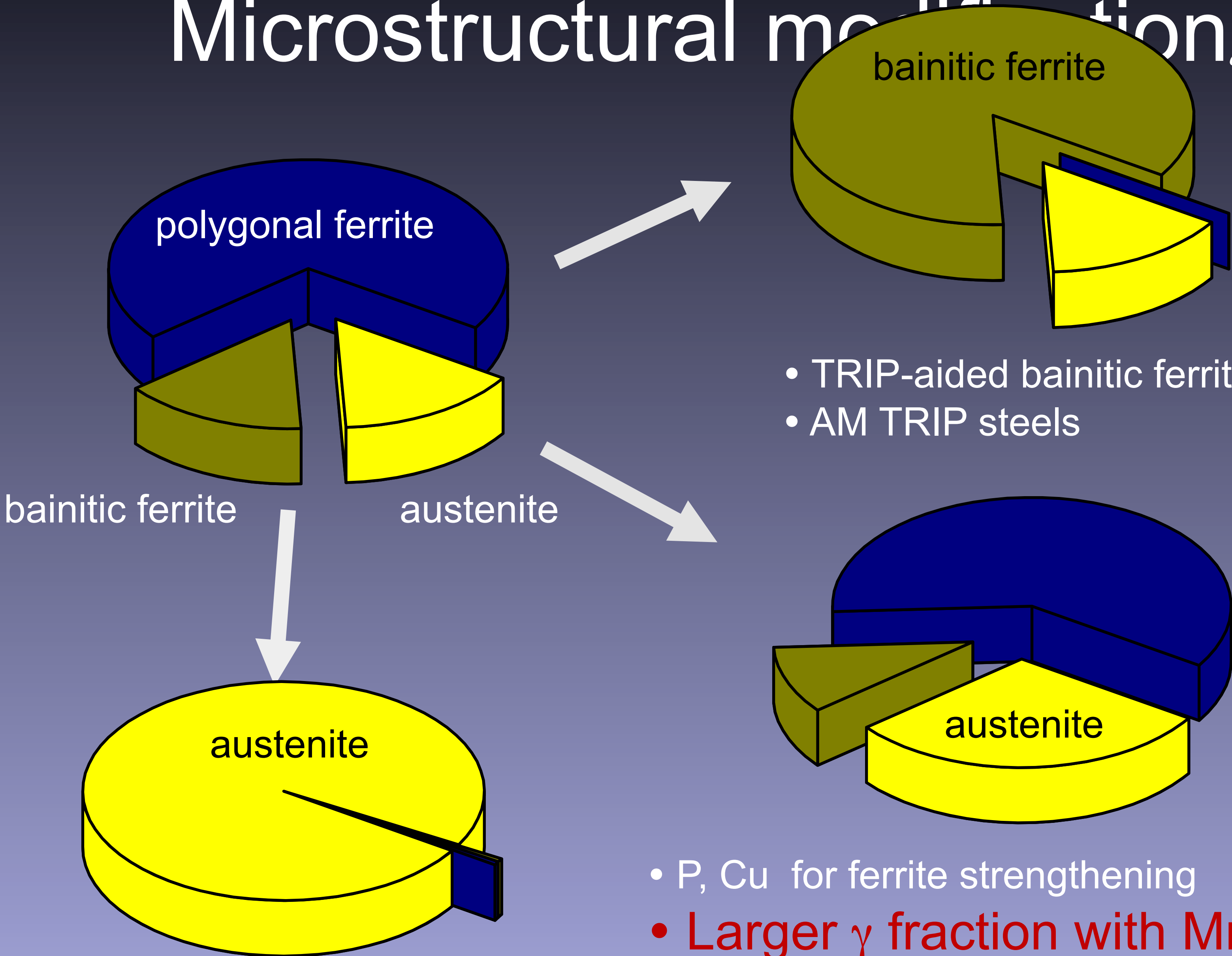
Excellent mechanical balance♪

- Typical phase fraction in conventional TRIP steels

: polygonal ferrite, 70~80%
  bainitic ferrite, 10~15%
  retained austenite, 10~15%



Microstructural modification♪



- TRIP-aided bainitic ferrite steels
- AM TRIP steels

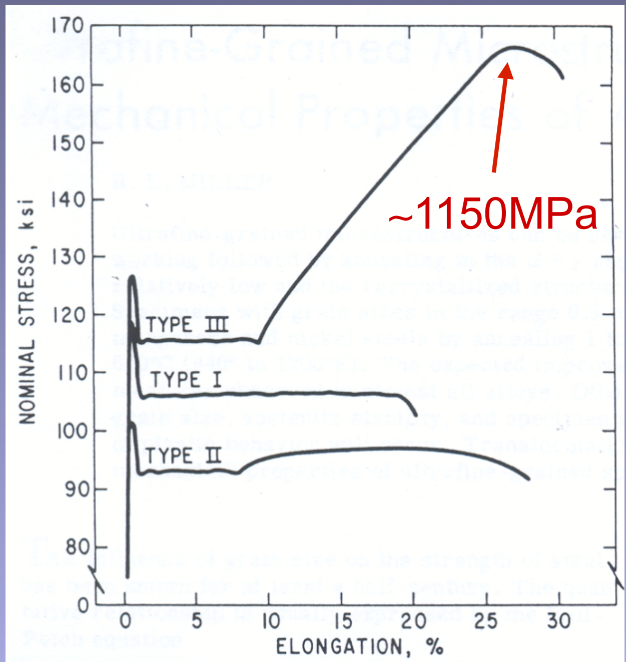
- P, Cu for ferrite strengthening
- Larger γ fraction with Mn (4~8wt%)

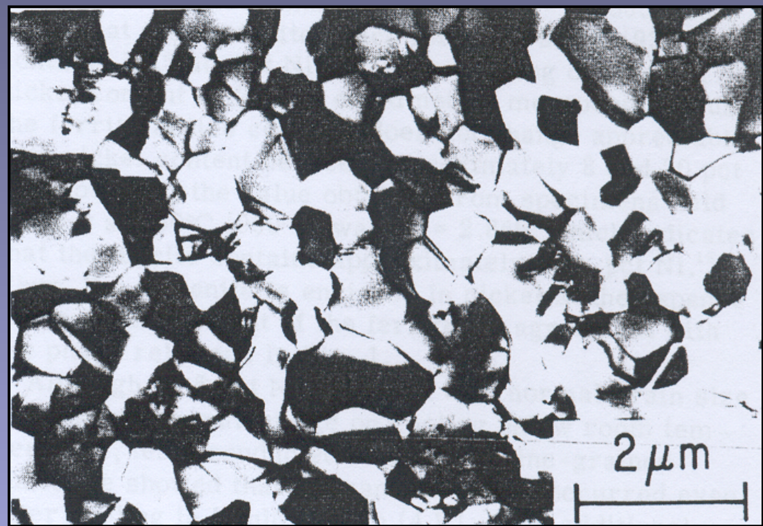
- Metastable austenitic steel (Fe-C-Ni-Cr-Mn)
- High Mn TRIP steel (>10wt%)

Medium manganese TRIP steels♪

- 0.1C-6Mn based alloy introduced by R.L Miller in 1972
- Annealing of cold-rolled martensite
- Micro-duplex structure : polygonal ferrite, 60~70%
  retained austenite, 30~40%

R.L. Miller, *Metall. Trans*., 3 (1972) 905.





Fe-0.11C-5.7Mn
Annealed for 16h at 600°C

Application of continuous annealing♪

Recrystallization of ferrite

Annealing temperature

Reverse transformation of austenite

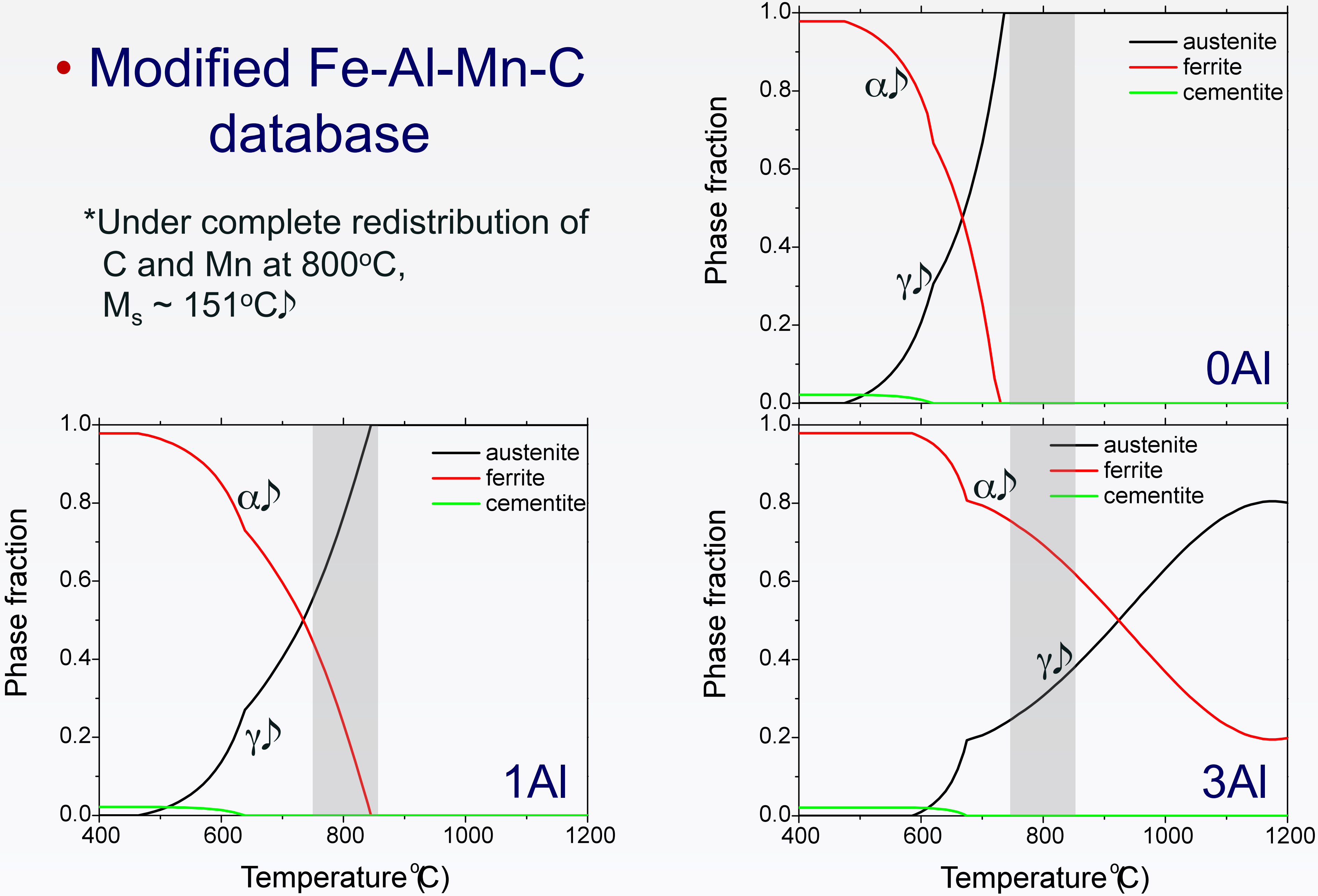
- Strategy and approach
  - suppression of extra-formation of austenite at higher temperature permitting recrystallization

→ Aluminum addition

Fe-0.12C-5Mn-Al

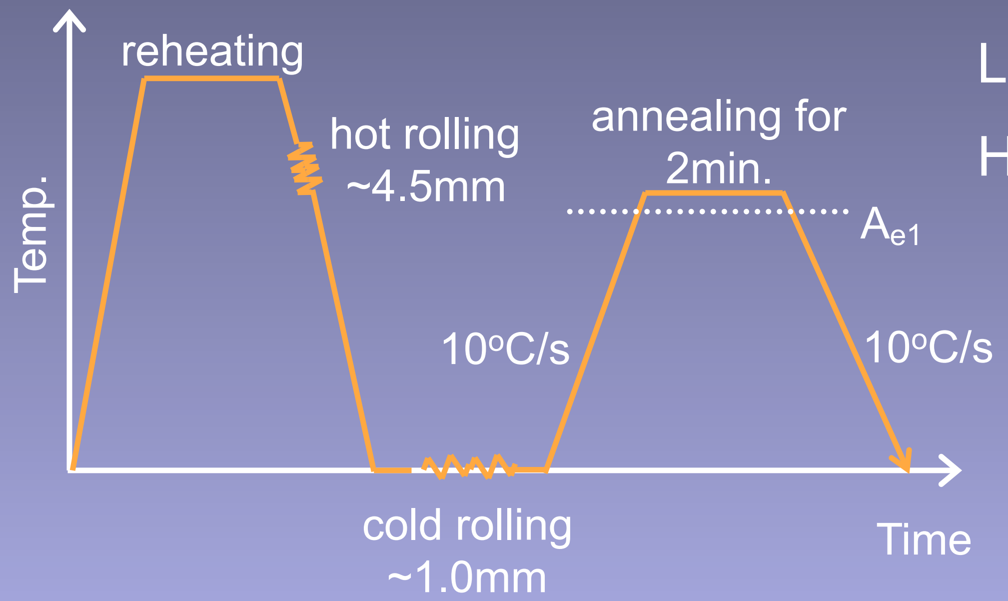
- Modified Fe-Al-Mn-C database

*Under complete redistribution of C and Mn at 800°C, M_s ~ 151°C



Alloys to investigate Al effect

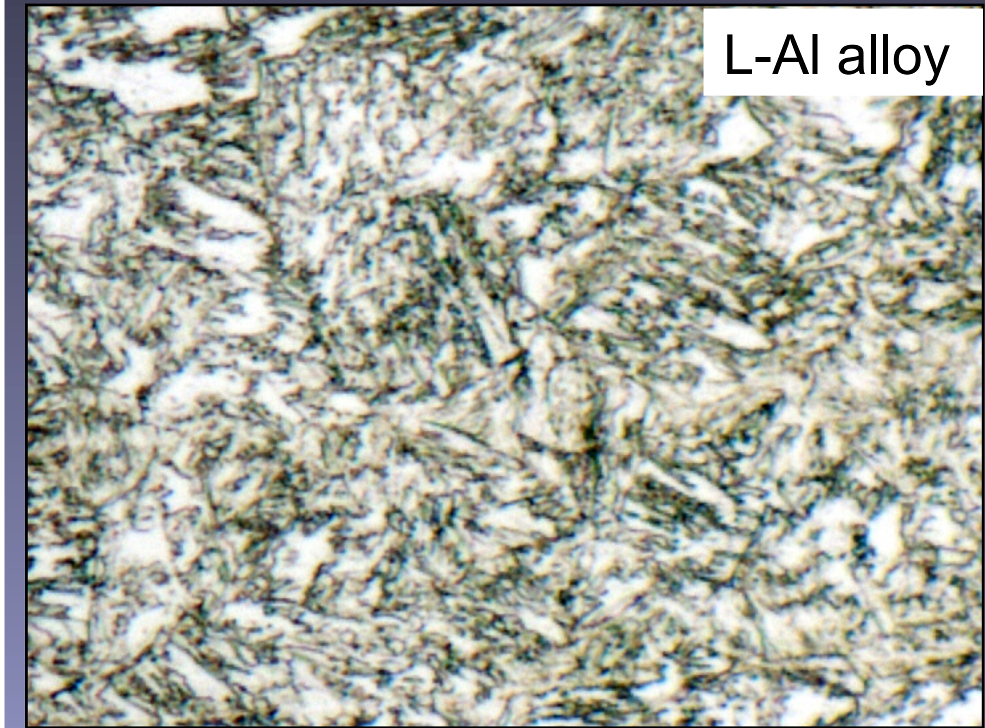
	C	Mn	Si	Al (wt.%)
L-Al	0.12	4.6	0.55	1.1
H-Al	0.12	5.8	0.47	3.1

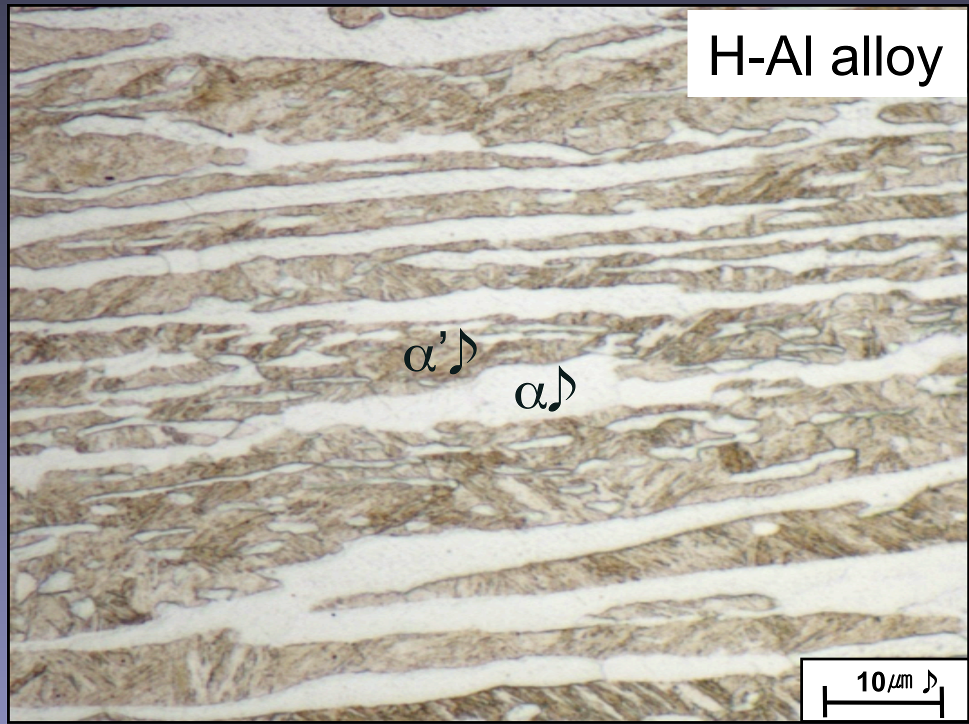


L-Al, 660, 720, 780°C♪

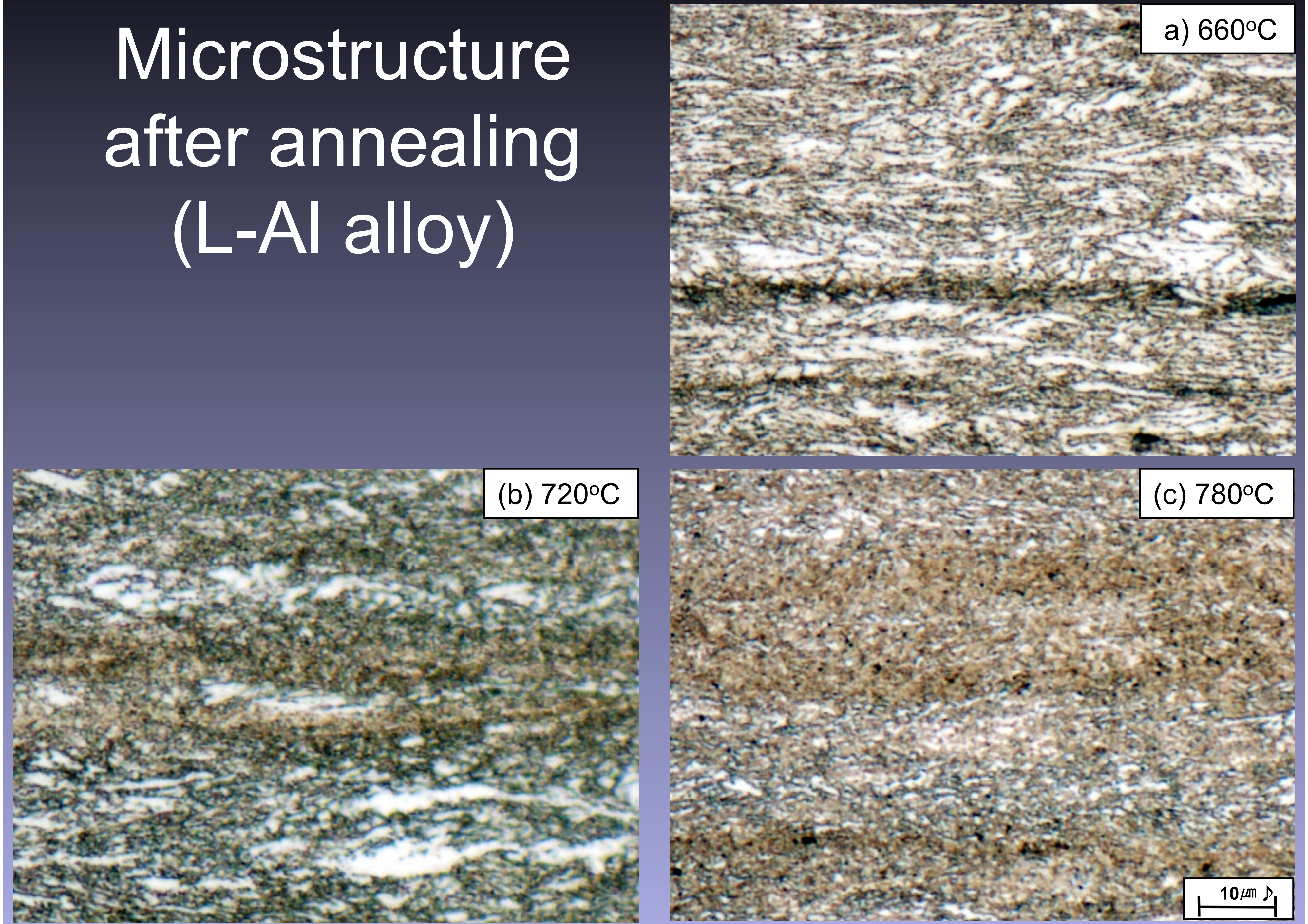
H-Al, 720, 780, 840°C♪

Microstructure after hot-rolling

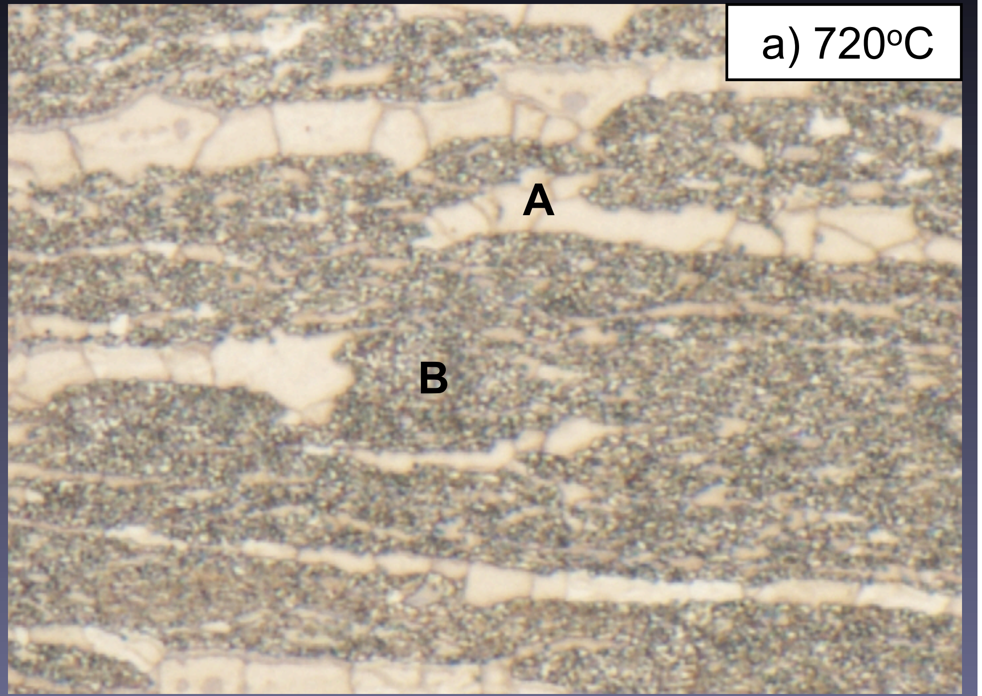


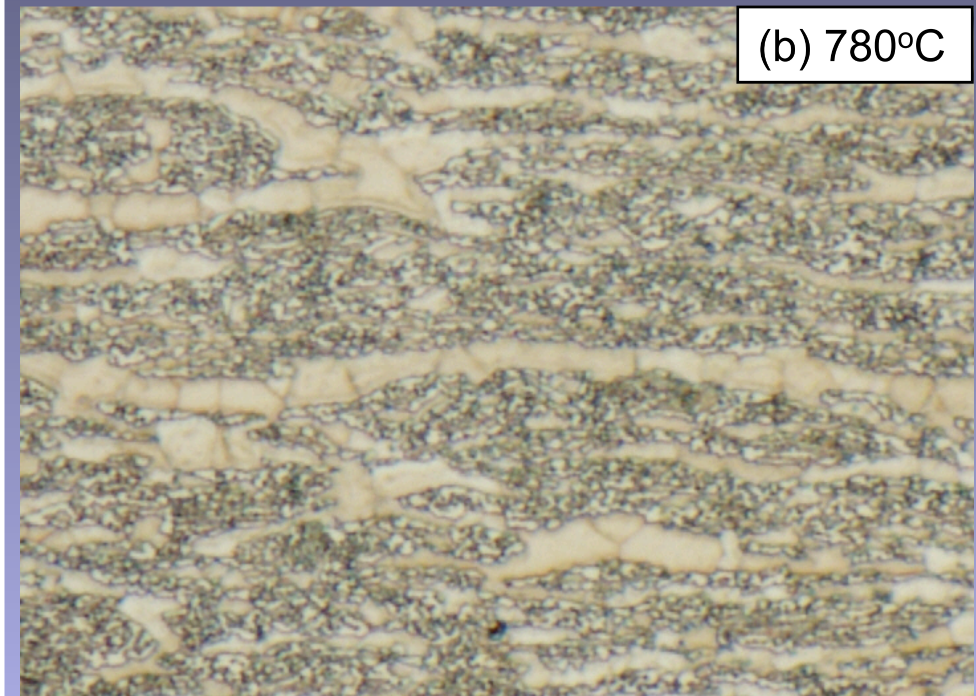


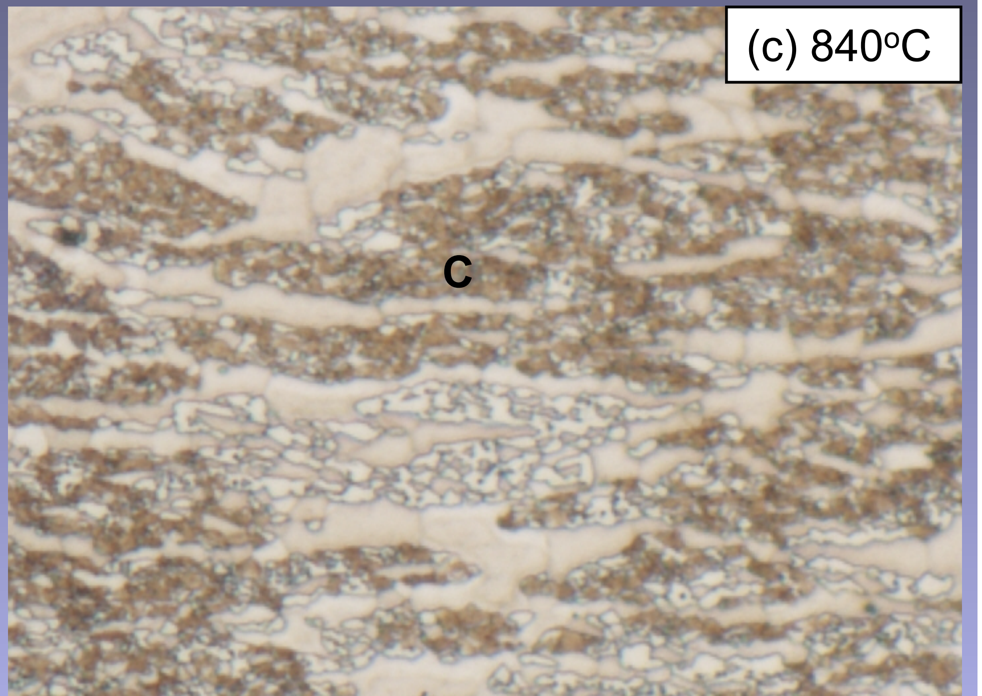
Microstructure after annealing (L-Al alloy)



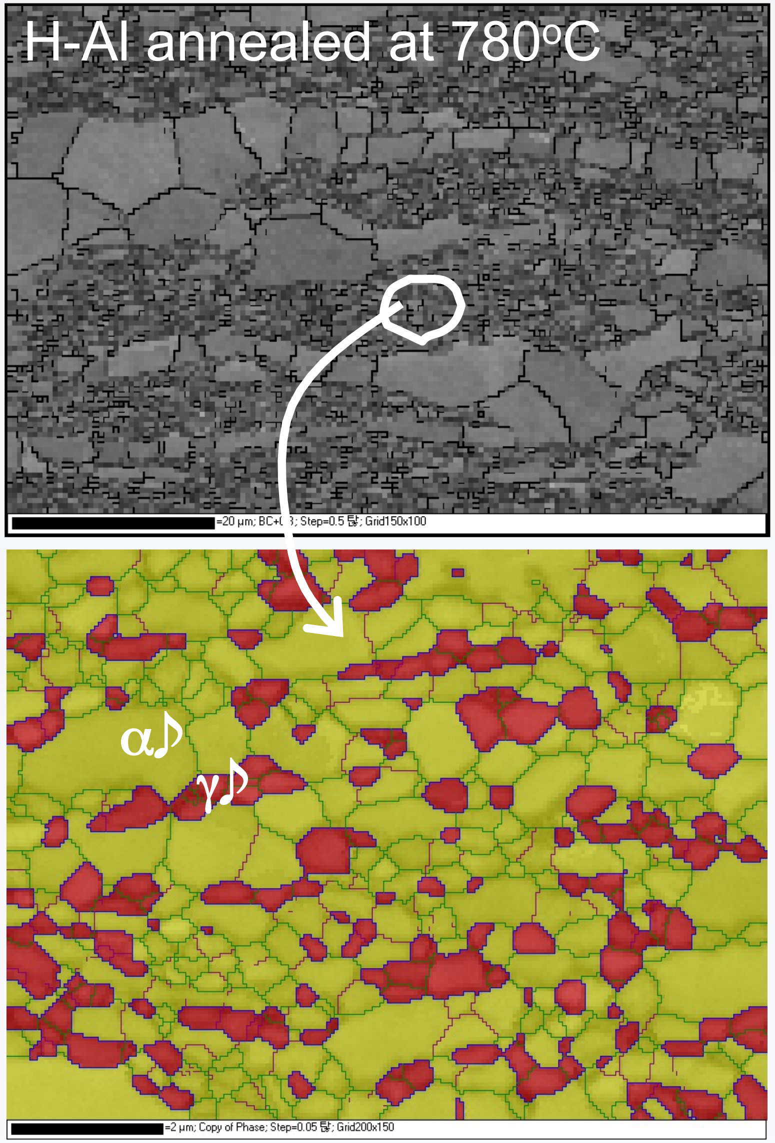
Microstructure after annealing (H-Al alloy)

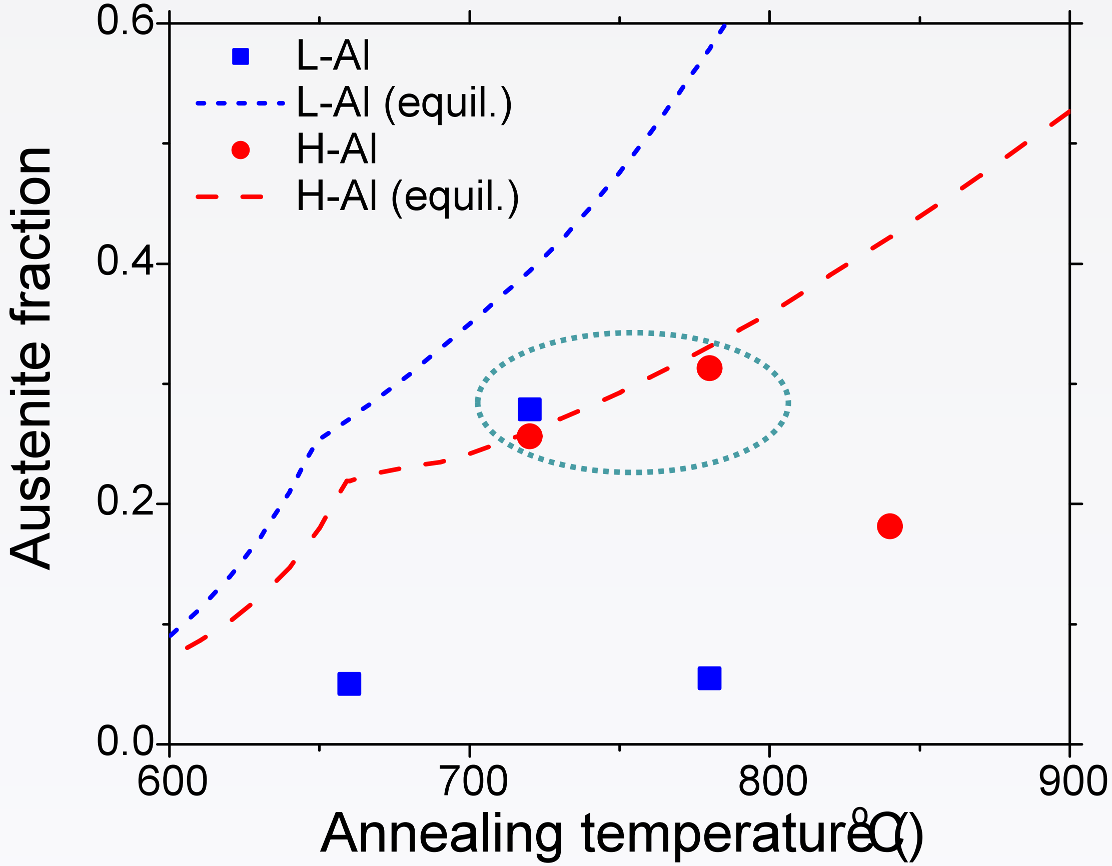




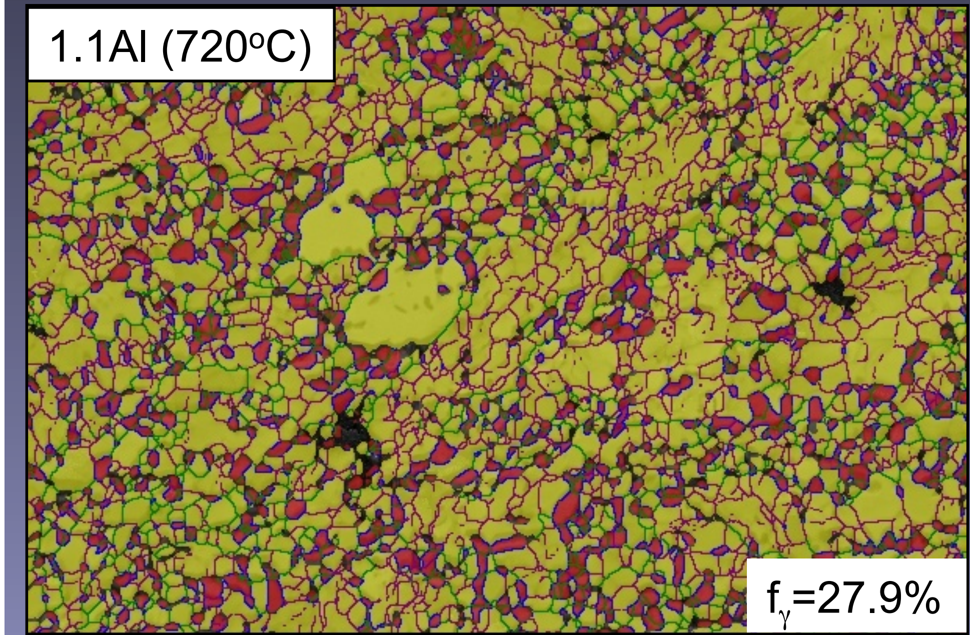


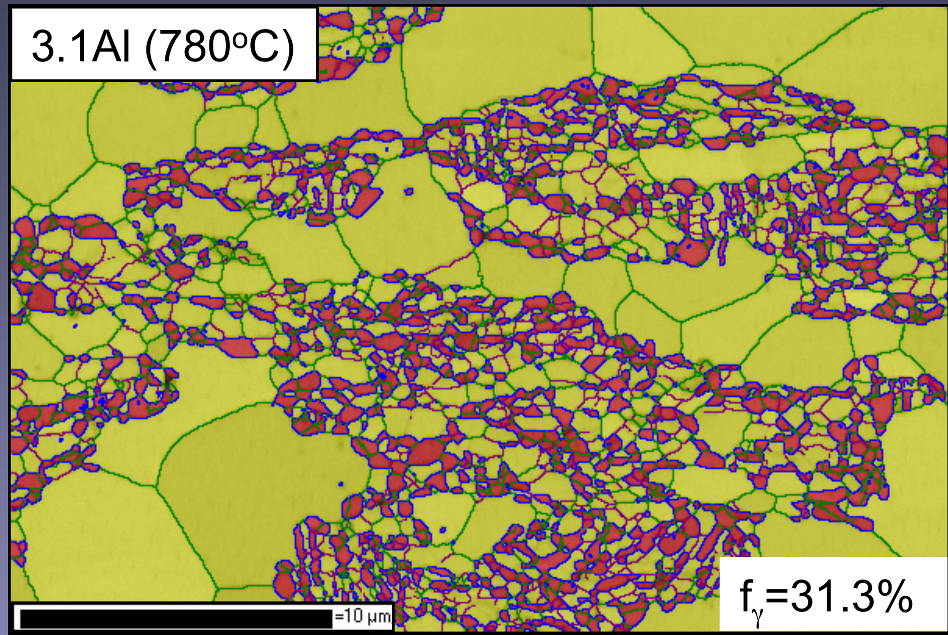
Retained austenite





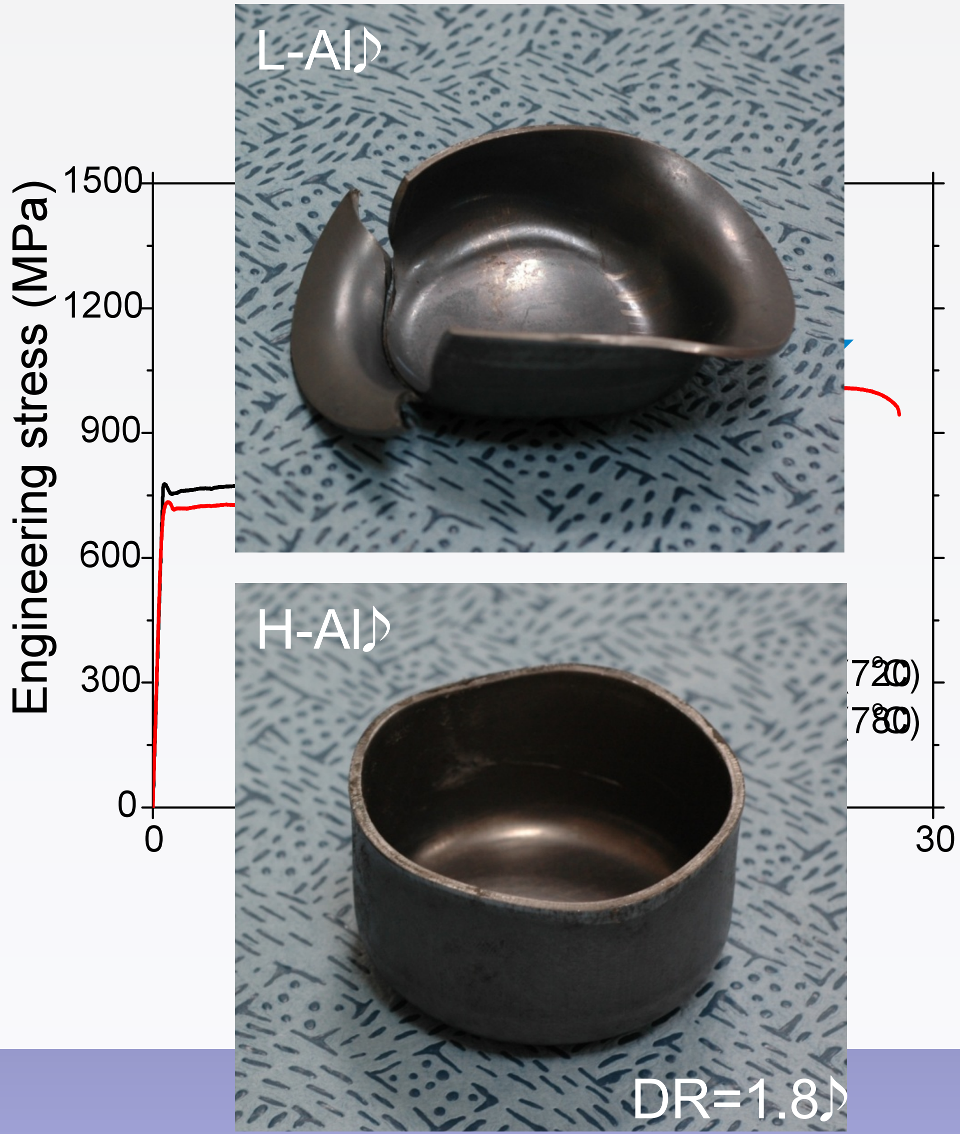
Phase maps of annealed sheets

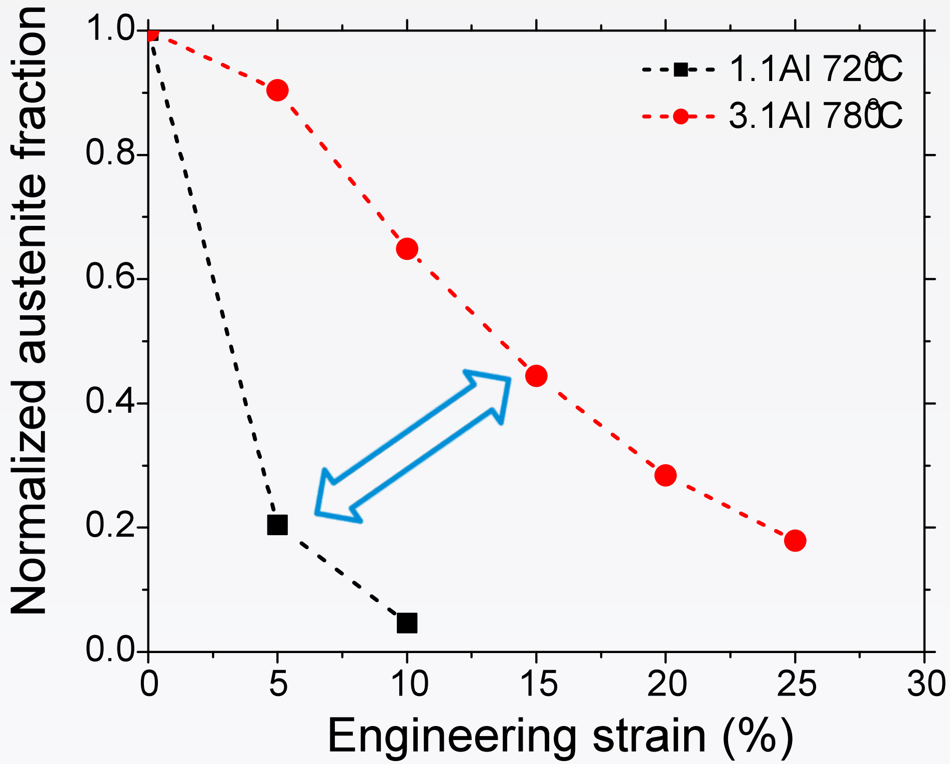




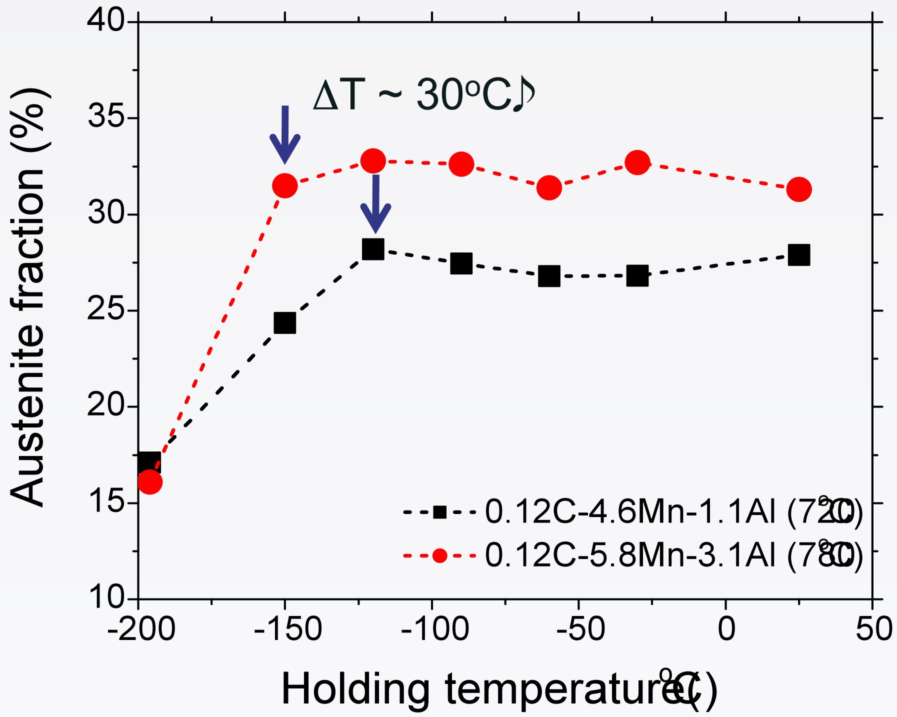
Fine-grained structure of
austenite♪

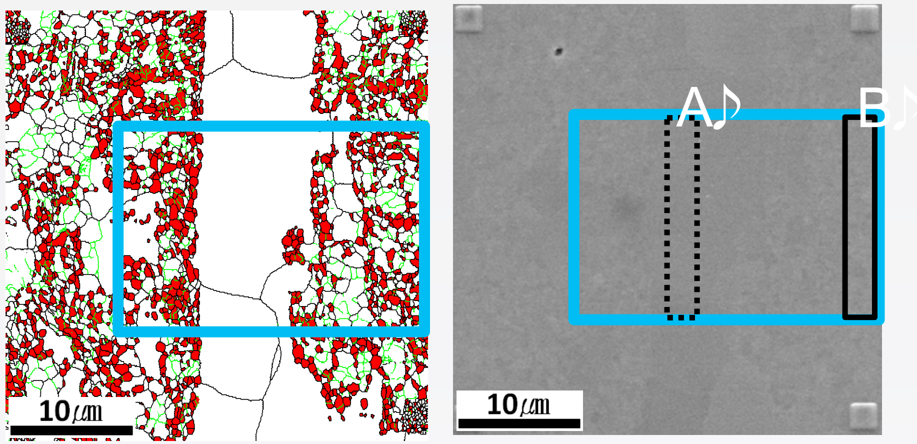
Mechanical behaviors

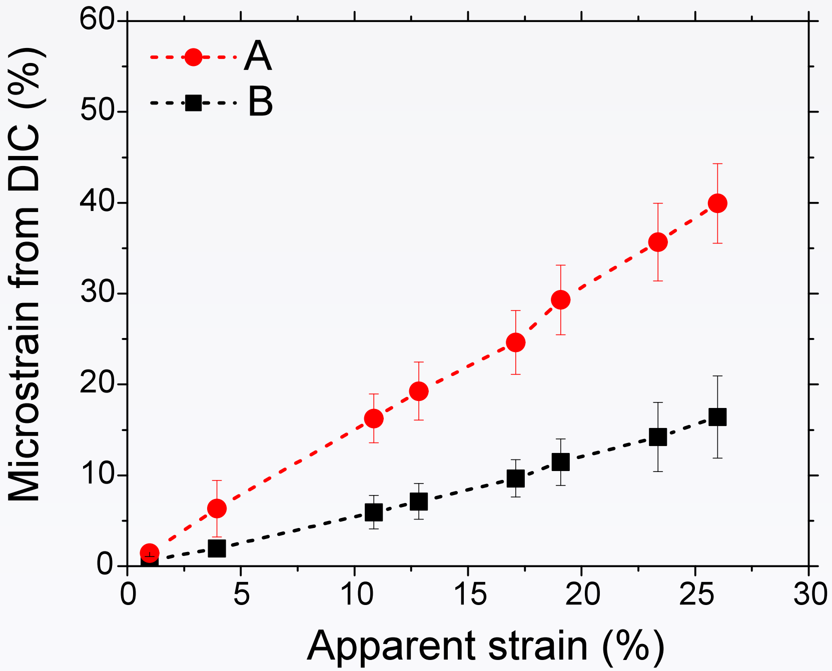




Mechanical stability of austenite







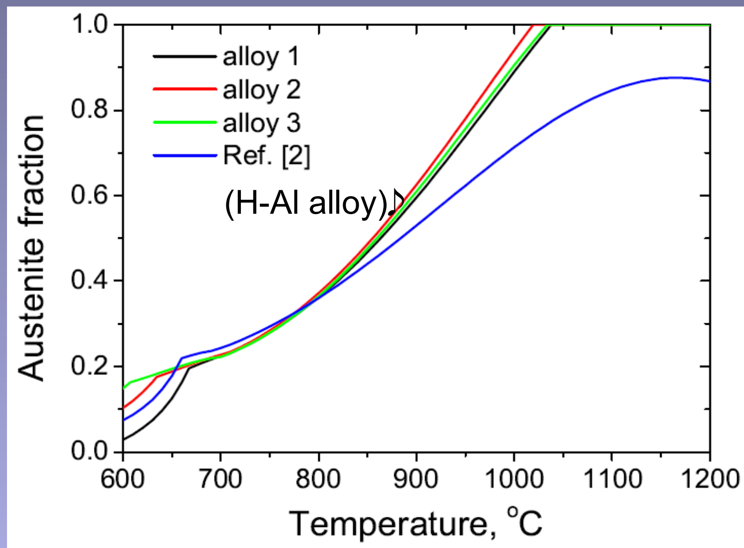
C and Mn balance in Al-reduced steels

- High Al content in steel♪

  - interaction with mold flux during continuous casting
  - interaction with refractory

- Reduced Al in alloy design♪

  - reduced C or Mn to maintain austenite fraction and stability at intercritical annealing

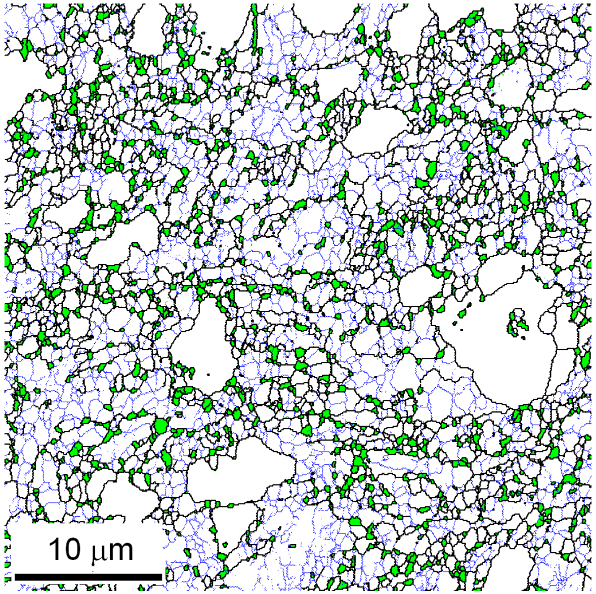


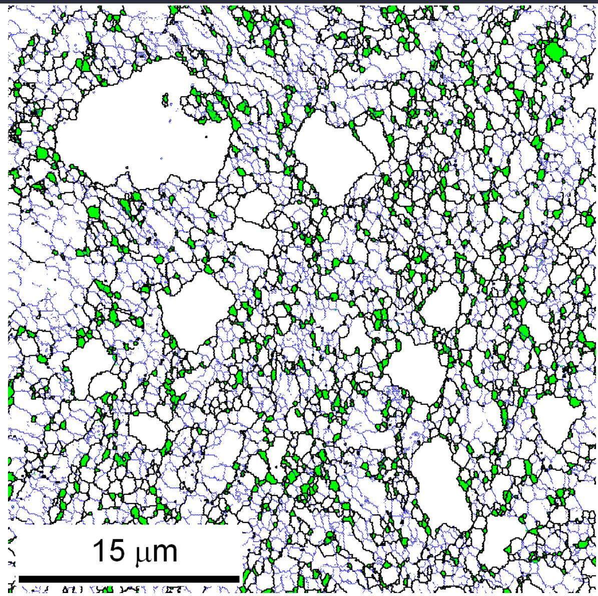
Investigated alloys

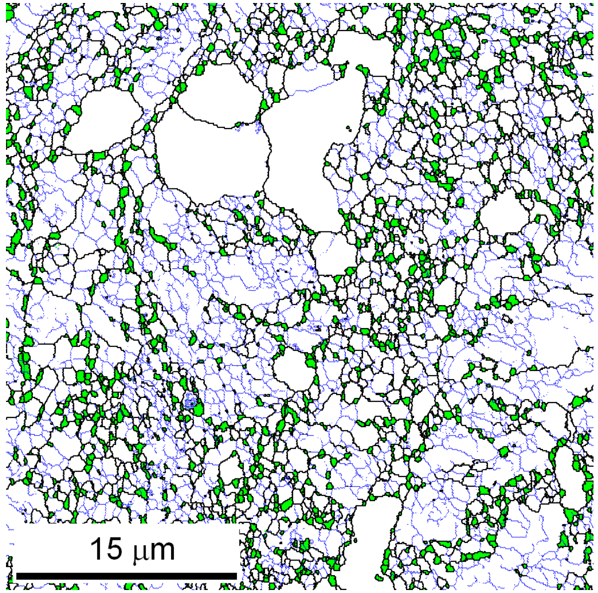
	C (wt. %)	Mn	Si	Al
Alloy 1	0.11	4.5	0.45	2.2
Alloy 2	0.075	5.1	0.49	2.1
Alloy 3	0.055	5.6	0.49	2.1

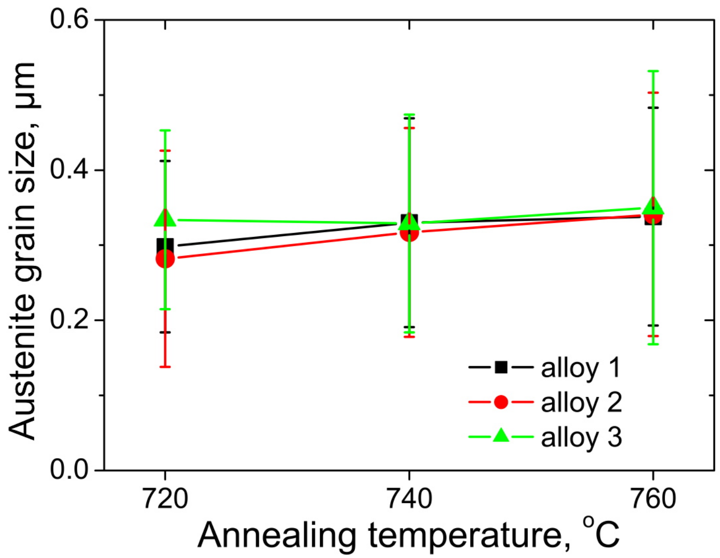
* H-Al, 0.12C - 5.8Mn - 0.47Si - 3.1Al♪

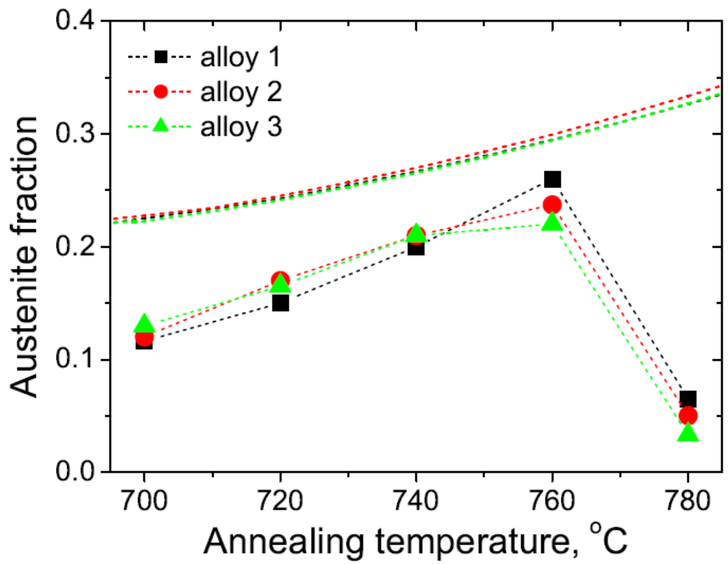
Microstructures of annealed alloys♪



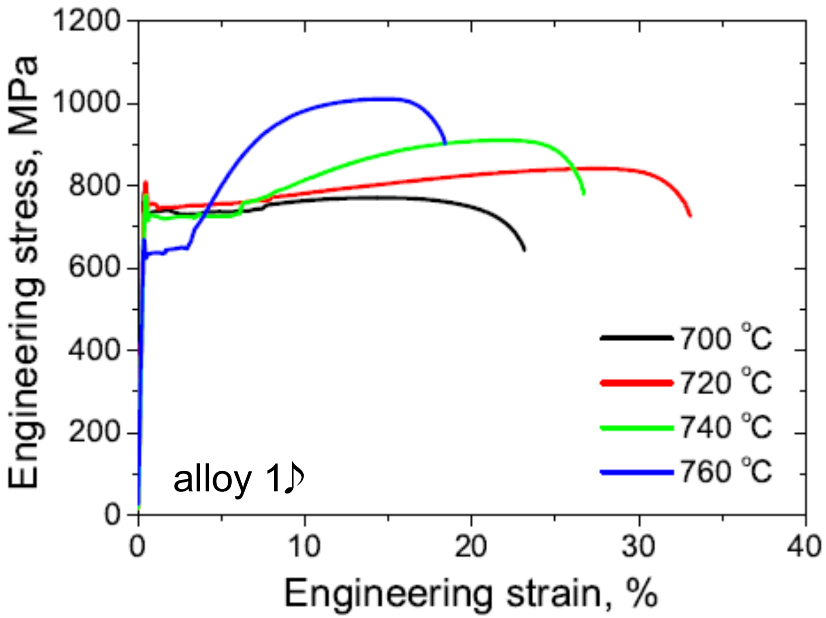


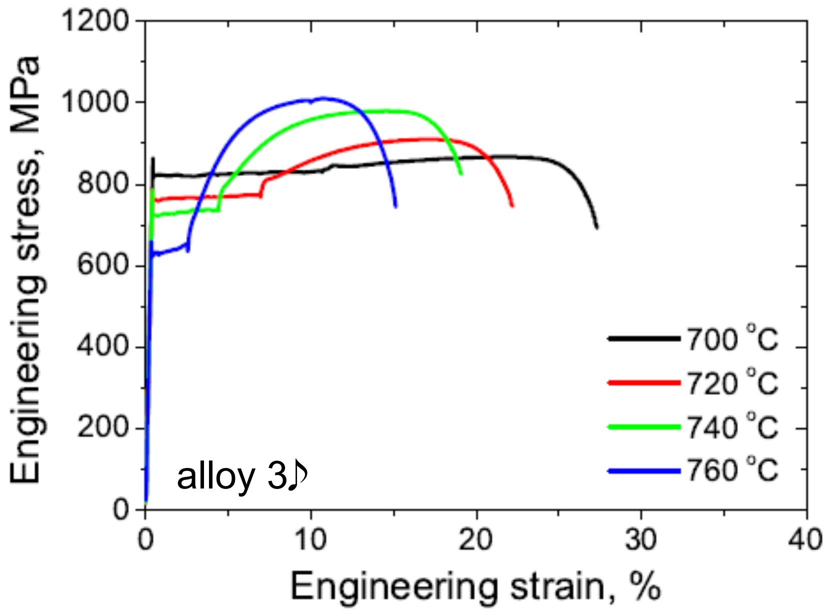




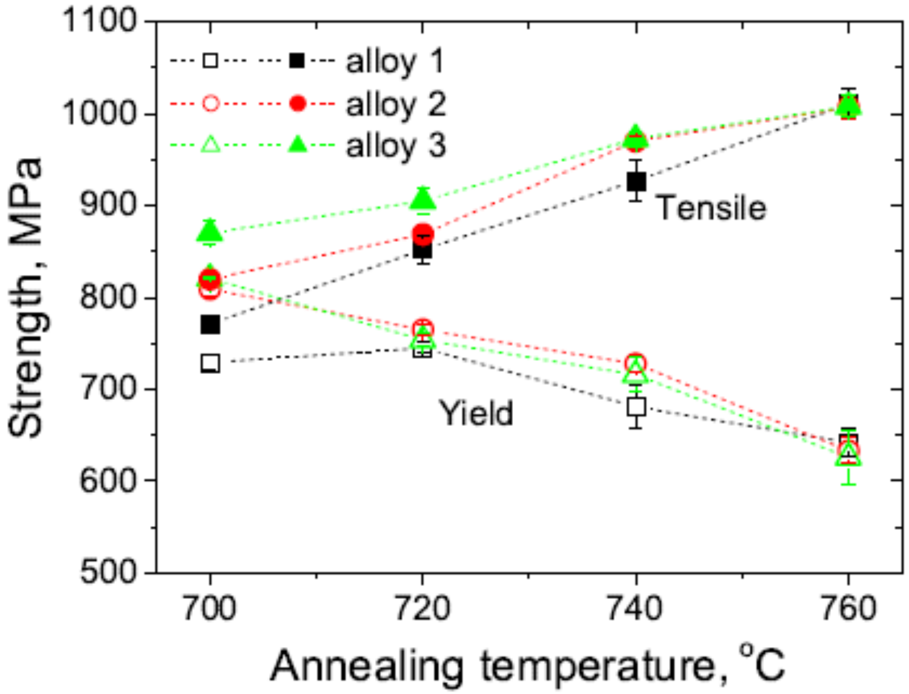


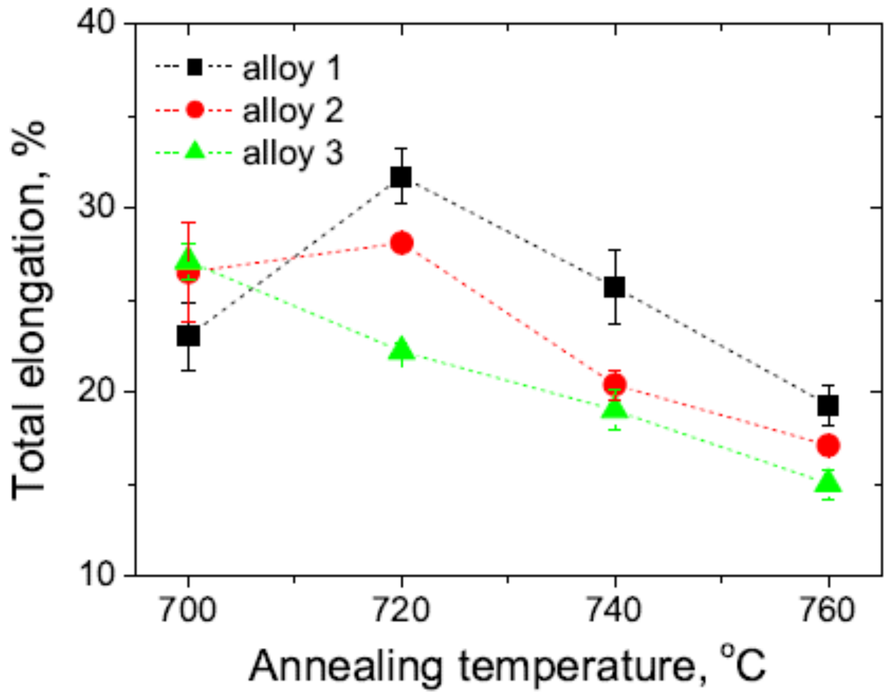
Mechanical properties♪



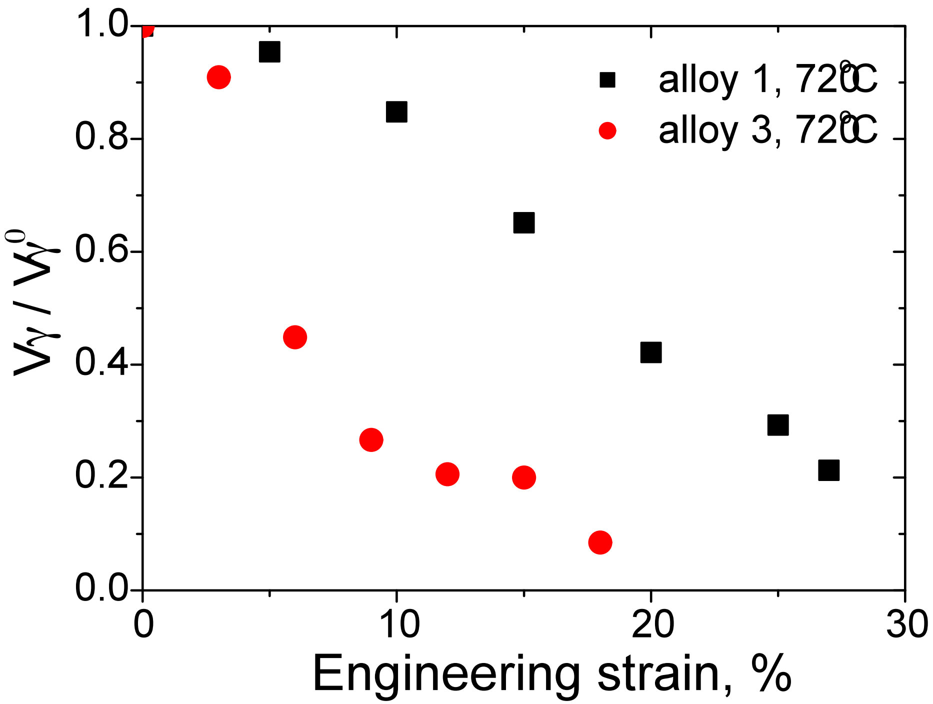


Mechanical properties♪





Kinetics of martensite transformation♪



- Influence of austenite composition on the martensite formation kinetics♪

(M. Sherif et al., Materials Science and Technology, 2004)♪

$$\frac{V_\gamma}{V_\gamma^0} = \exp\left(-k_1 \Delta G^{\gamma\alpha'} \varepsilon\right)$$

$$\Delta G^{\gamma\alpha'} = G^{\gamma} - G^{\alpha'}$$

- Influence of grain size on decrease of M_s temperature♪

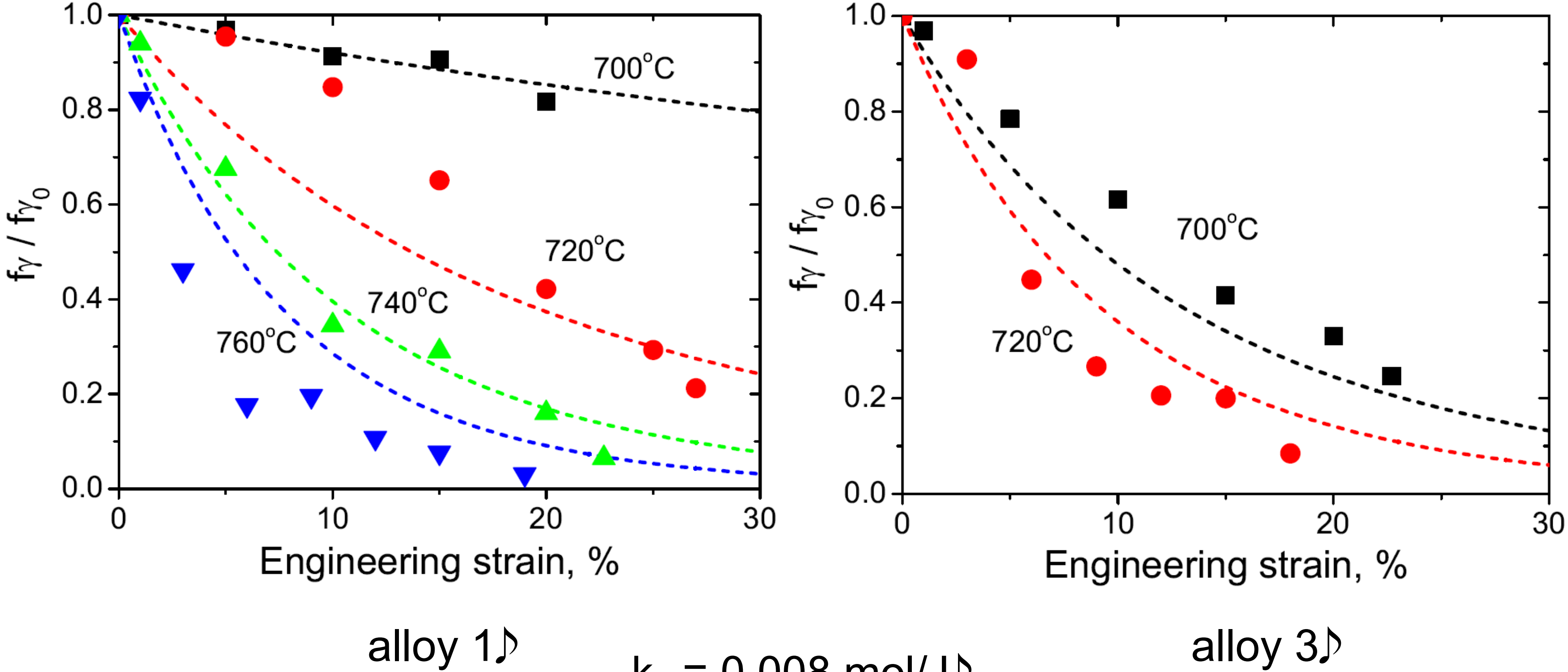
(H. S. Yang et al., Scripta Materialia, 2009)♪

$$M_s^0 - T = \frac{1}{b} \ln\left[\frac{1}{aV}\left\{\exp\left(-\frac{\ln(1-f)}{m}\right) - 1\right\} + 1\right]$$

V : average volume of an austenite grain
f : first detectable martensite fraction, 0.01
m : aspect ration of marteniste plate, 0.05♪

Influence of grain size on M_s temperature decrease is converted into extra free energy required for the martensite transformation♪

Kinetics of martensite transformation



$k_1 = 0.008$ mol/J

- Since the grain size of austenite is similar in all alloys, the mechanical stability of austenite is primarily affected by chemical effect
- Effect of carbon is more critical even though we can obtain similar fraction of austenite by altering C / Mn concentration

Summary♪

- Low carbon, medium Mn TRIP steel with Al

  - potential candidate for advanced TRIP steel
    showing improved mechanical balance ♪

- C / Mn balance in Al-reduced Mn TRIP steel

  - similar microstructure withcomparable austenite fraction
  - C has more critical effect on mechanical stability of
    austenite and thus uniform elongation♪