Development of Heat Treatable Magnesium-Lithium Alloys

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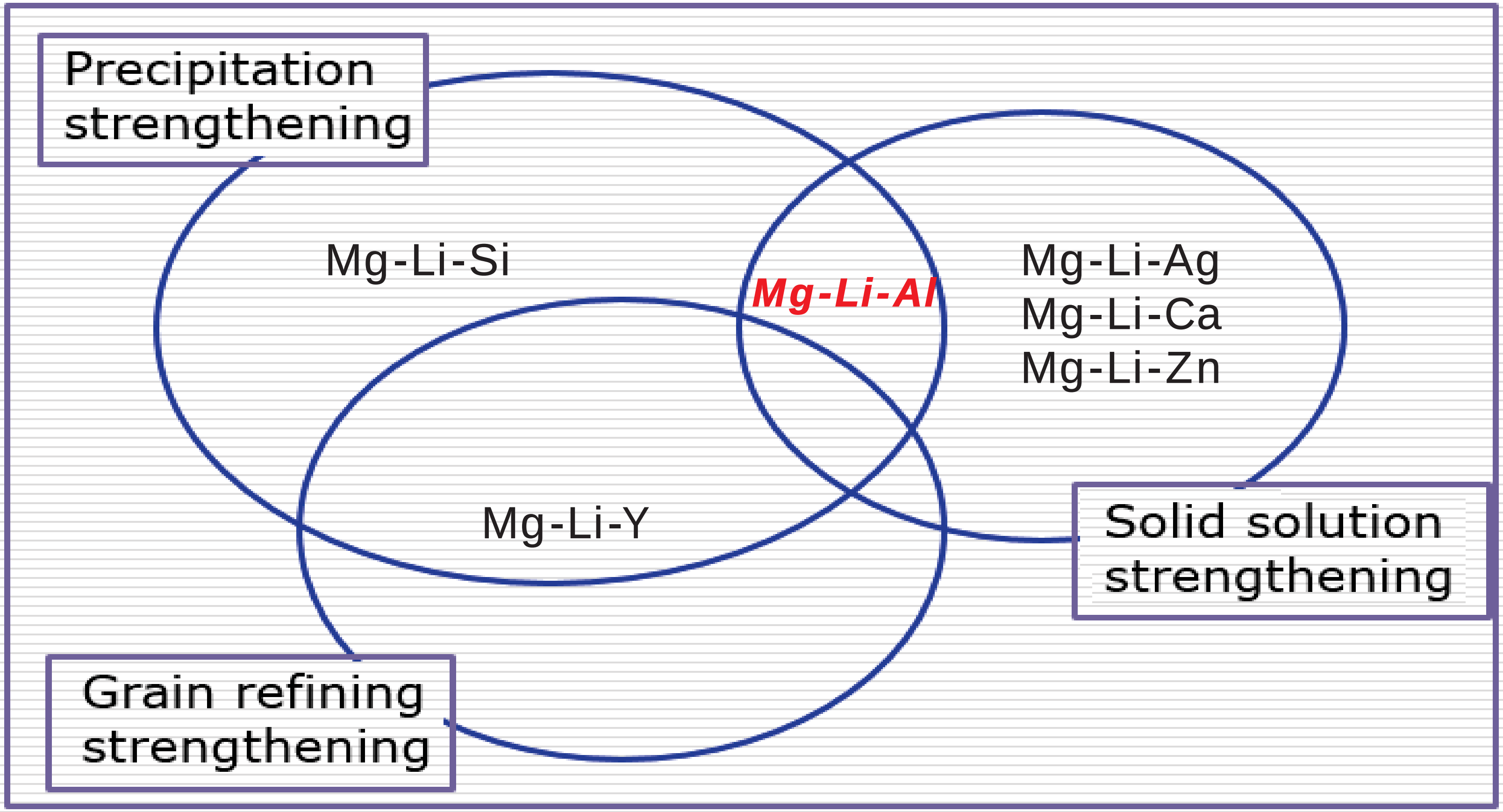
Background

- Magnesium-Lithium Alloy
  - Advantages
    - Low density, light weight
    - Damping capacity
    - Thermal conductivity
    - Formability, machinability
    - Electron-magnetic interference shielding
    - Recyclable
  - Disadvantage
    - Low recrystallization temperature leads to quick grain growth.
    - Compared to other light alloys, Mg alloy has low mechanical strength, which makes it improper for structural application purpose.

Mg Alloy Strengthening Mechanisms

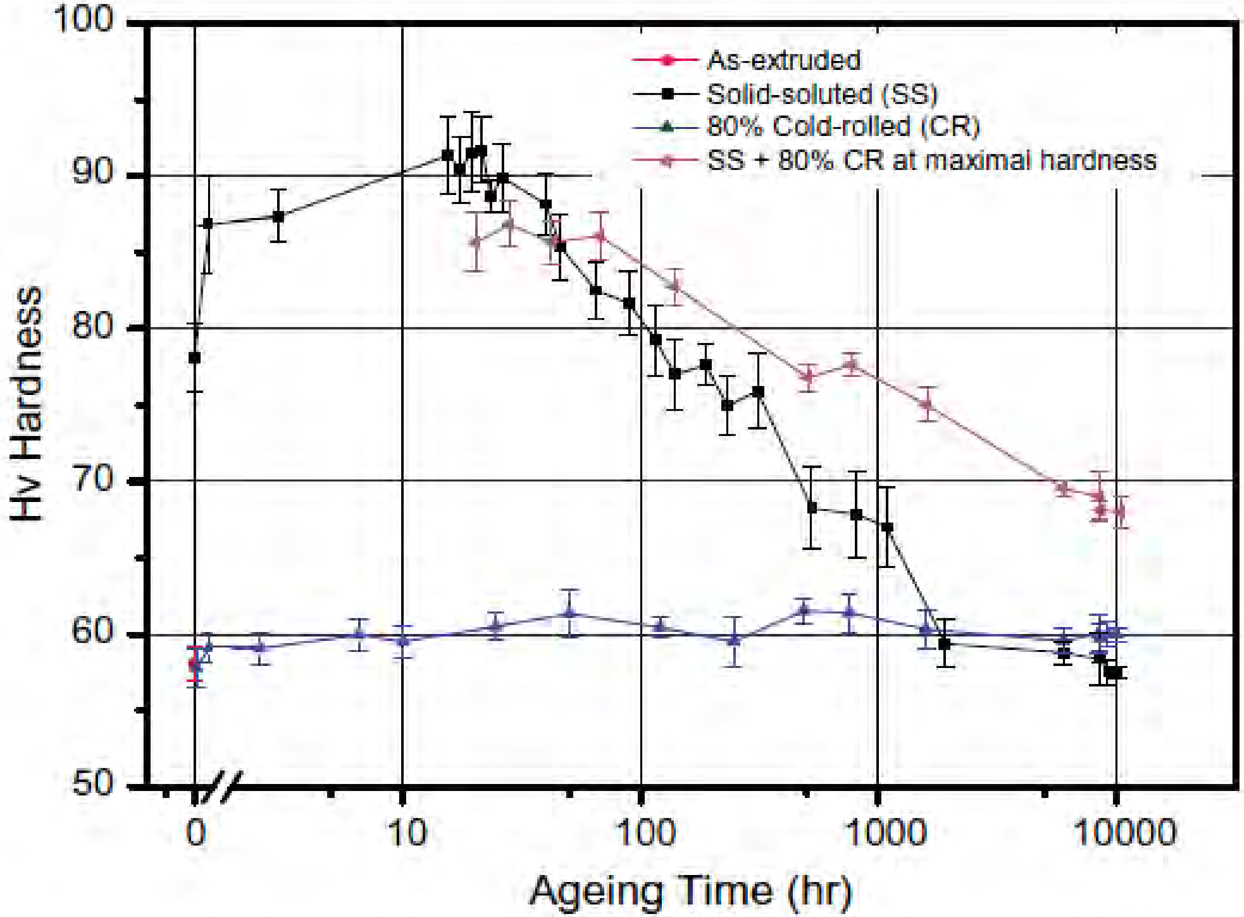


Compared to commercial magnesium alloy LZ91 (Mg-9wt%Li-0.7wt%Zn), three strengthening methods may be applicable to Mg-Li-Al alloy

S. Oki, M. Kamida, M. Tsutikawa, 產學連攜研究推進事業成果報告書, 平成 20 年度, P507-515.

Work Hardening vs. Solid Solution Strengthening

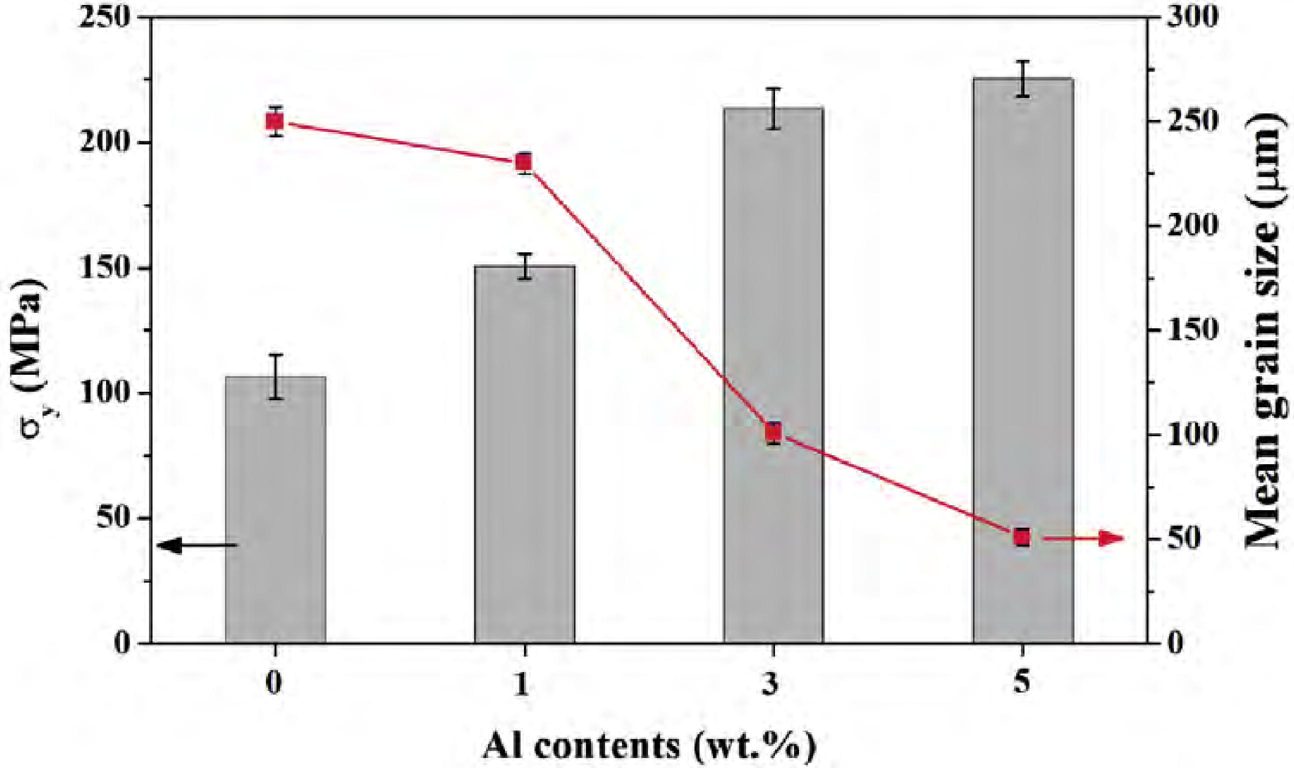
Under aging?   Peak?   Over aging?



The variation of the hardness with the room temperature aging time of 80% cold rolled and solid-solution treated LAZ1010 specimens.

S.K. Wu, Y.H. Li, K.T. Chien, C. Chien, C.S. Yang, X-ray diffraction studies on cold-rolled/solid–solution treated α+β Mg–10.2Li–1.2Al–0.4Zn alloy, Journal of Alloys and Compounds 563 (2013) 234–241

Grain Refining Strengthening



Yield strength (σ_y) and mean grain size obtained from the as-squeeze Mg-15Li-xAl (x = 0, 1, 3, and 5 wt%) alloys

Hardness(HV)	X=0	X=1	X=3	X=5
LA15x	64 ± 1.5	96 ± 0.1	100 ± 1.1	105 ± 0.8

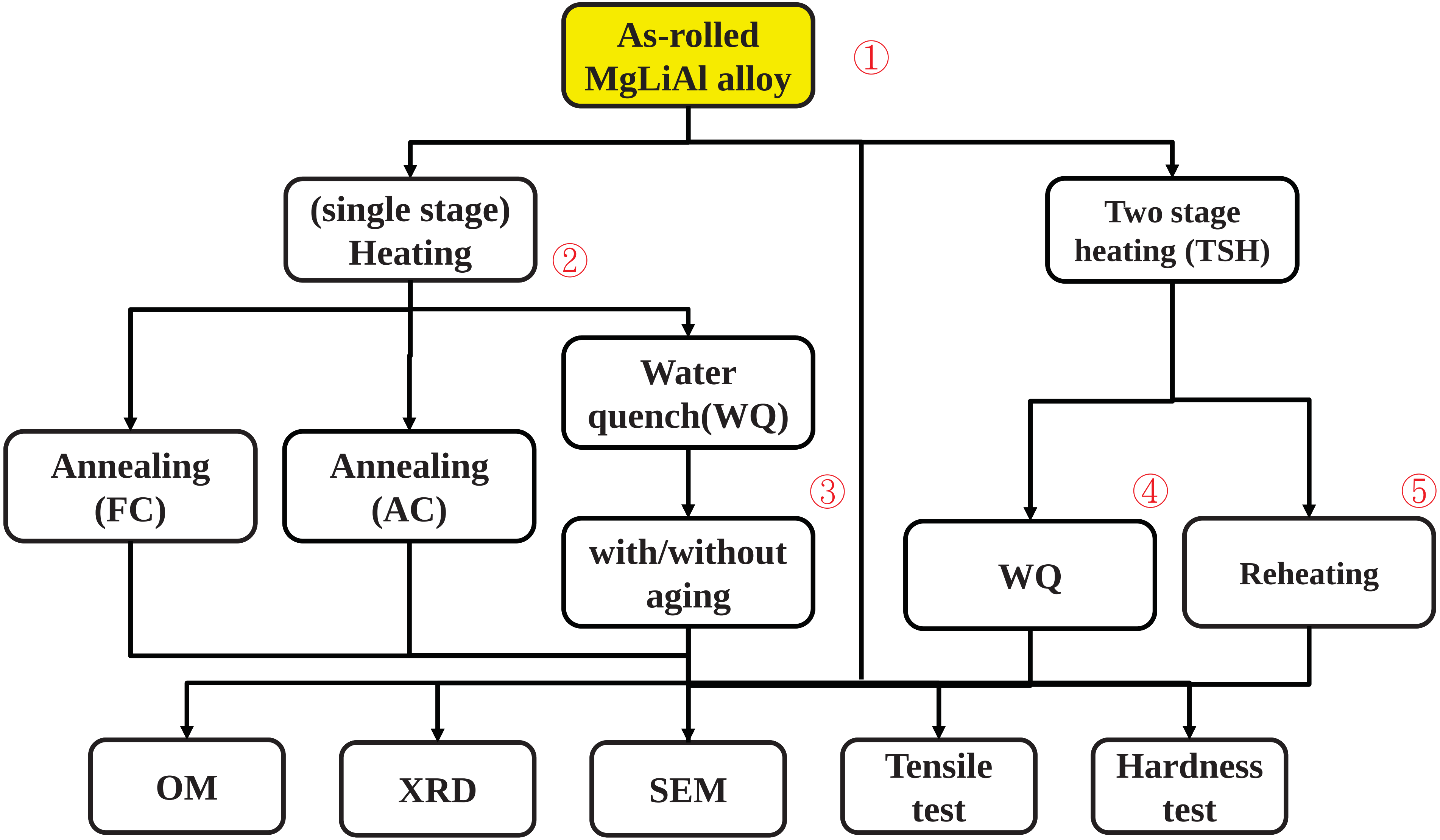
Park, G. H., et al. (2016). "Development of lightweight Mg Li Al alloys with high specific strength." Journal of Alloys and Compounds 680: 116-120.

Motivation

- Mg - Li - Al - Zn alloy
  - Try to elucidate the best strengthening method/mechanism
  - Different heat treatments were applied

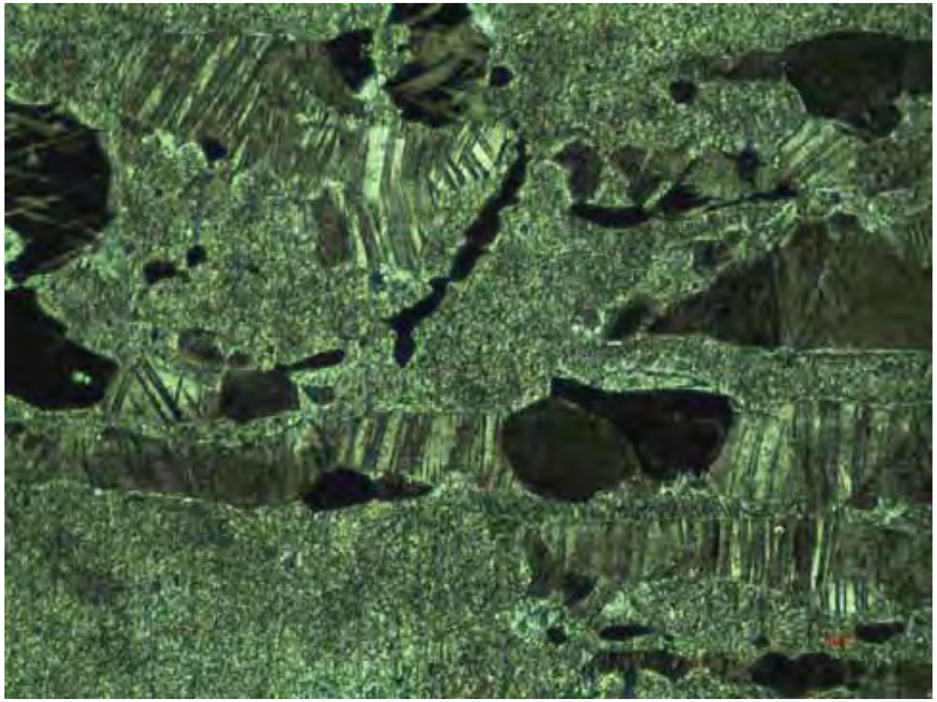
- Parameters
  - As-rolled alloy
  - Different cooling rates after heat treatment (solid solution)
  - Aging after water quench (WQ)
  - WQ after two stage heating (TSH)
  - Different heat treatments after WQ and TSH

Experimental

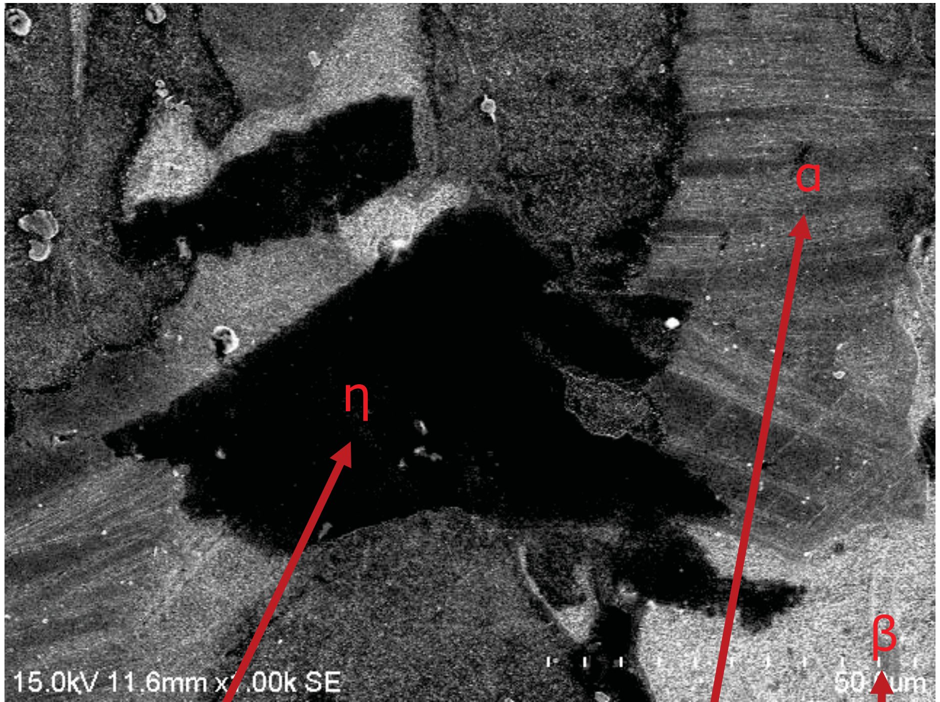


Microstructures of as-rolled MgLiAl alloy

OM



SEM



Hardness	HV
α Phase (Mg-rich)	66
β Phase (Li-rich)	56
η Phase (AlLi)	77

η:

Element	Weight%
Mg K	87.16
Al K	12.84
Totals	100.00

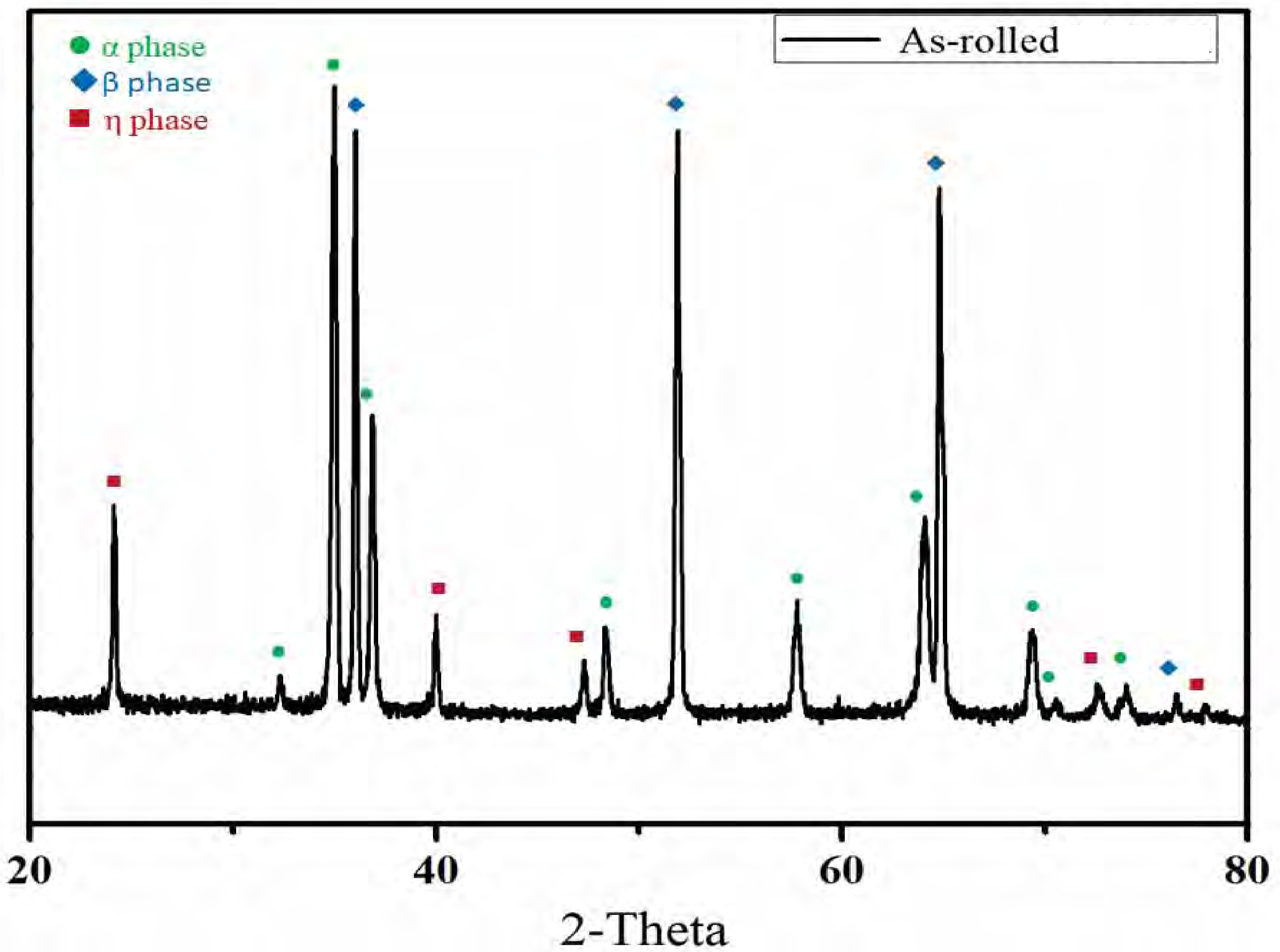
α:

Element	Weight%
Mg K	97.70
Al K	2.30
Totals	100.00

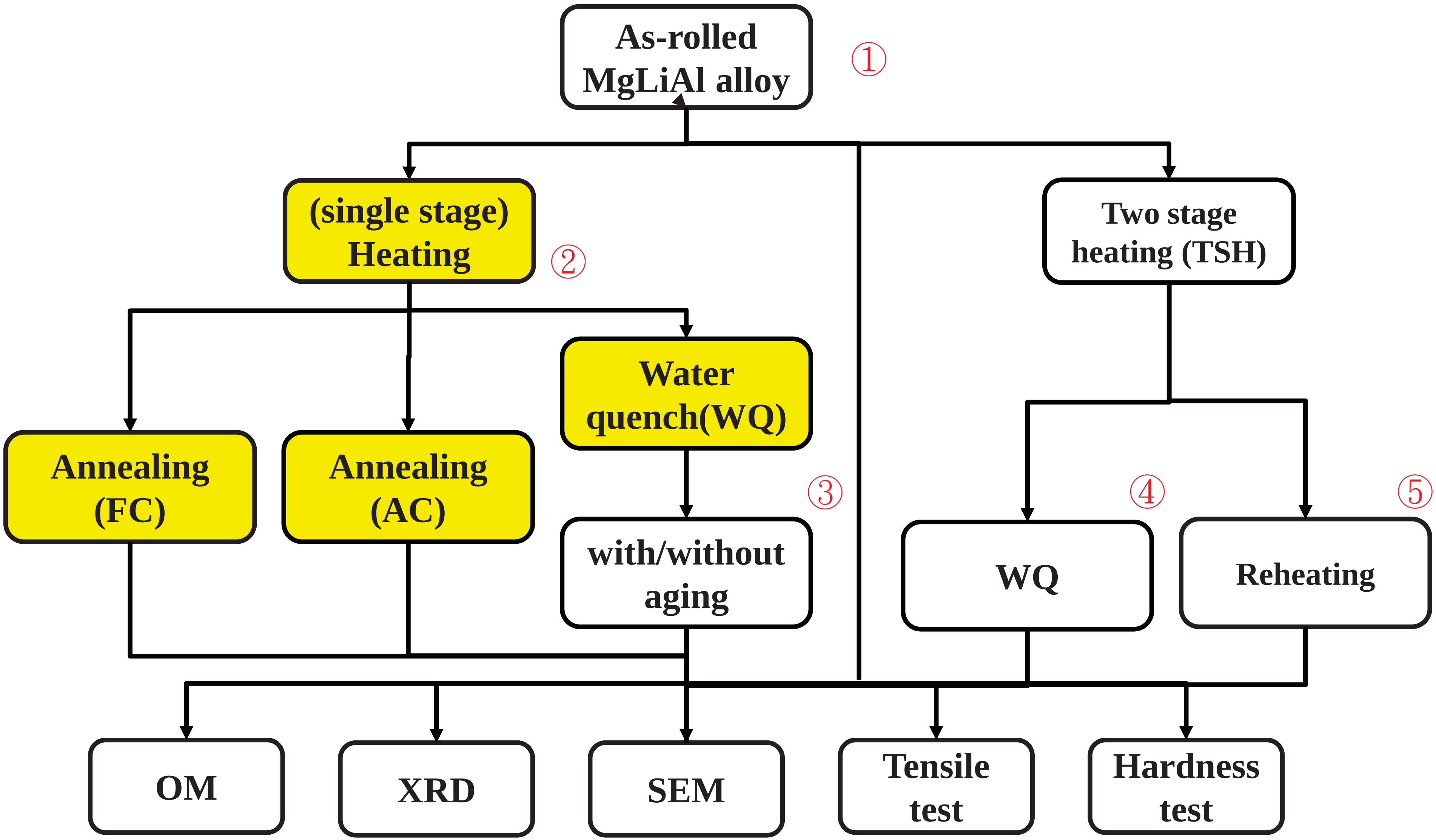
β:

Element	Weight%
Mg K	96.70
Al K	3.30
Totals	100.00

XRD of as-rolled MgLiAl alloy

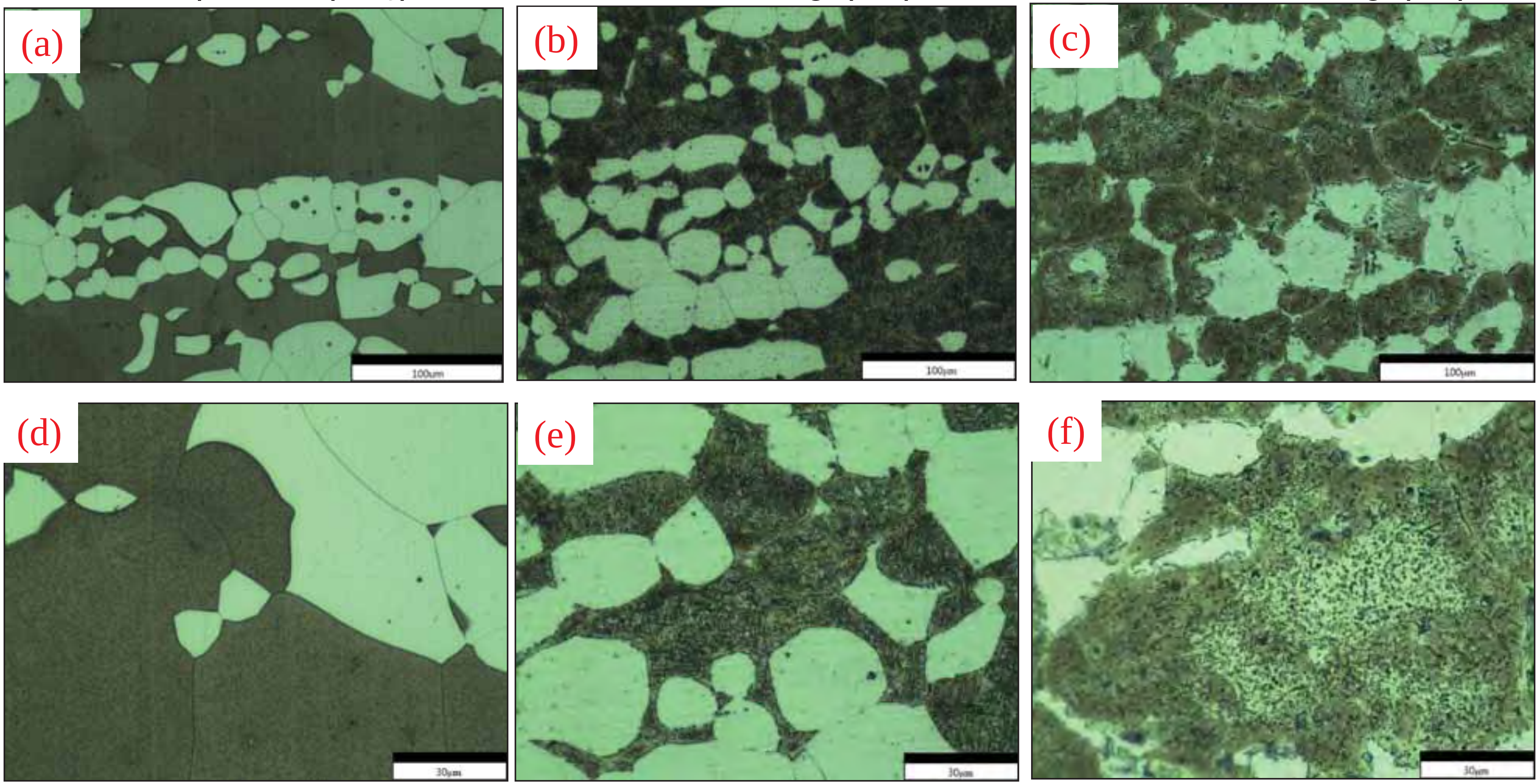


Experimental



Effect of cooling rate on microstructure

Water quench (WQ) Air cooling (AC) Furnace cooling (FC)

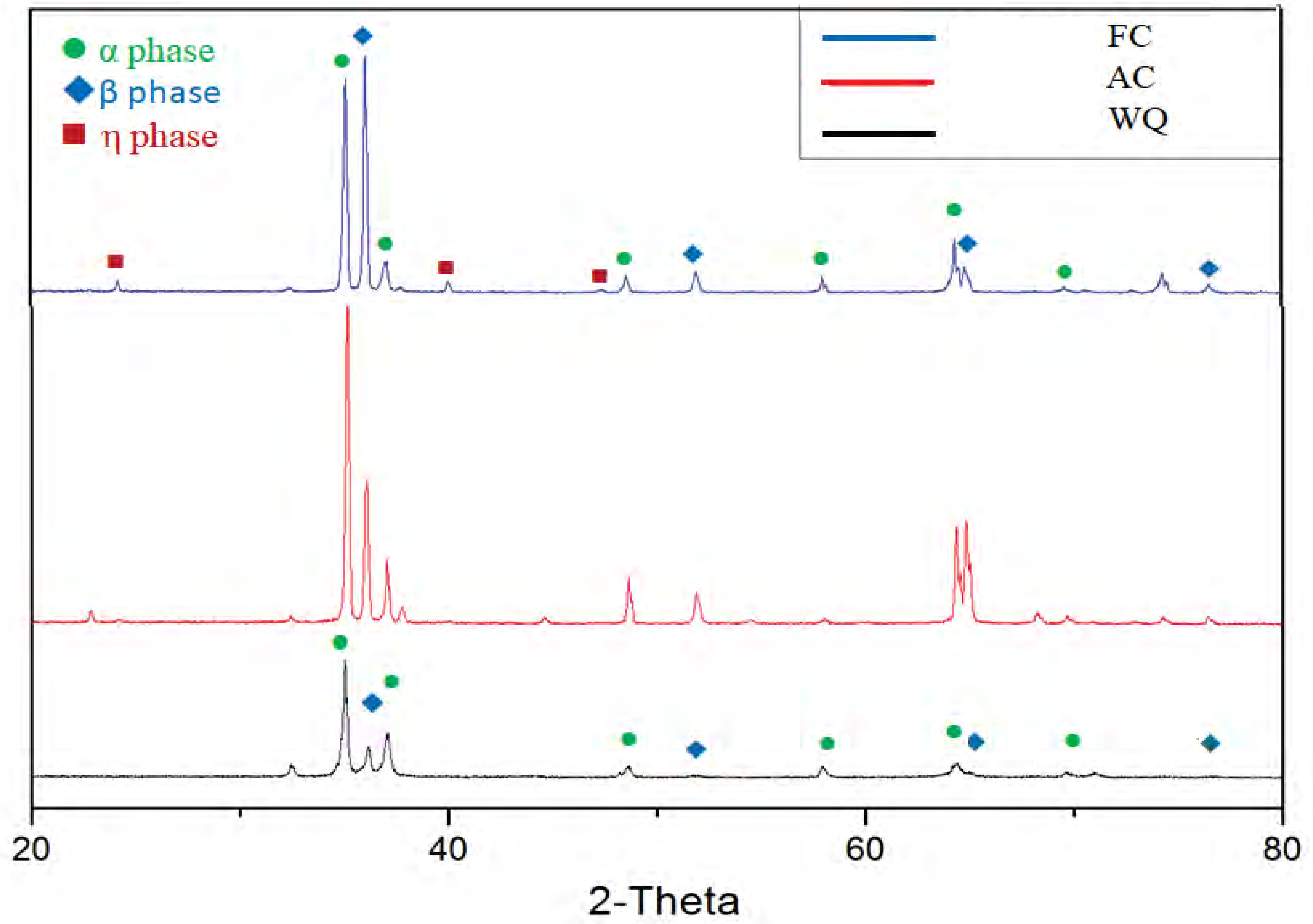


2 phases in WQ (fast cooling) 3 phases in AC and FC (slow cooling)

Cooling from 400°C x 30min

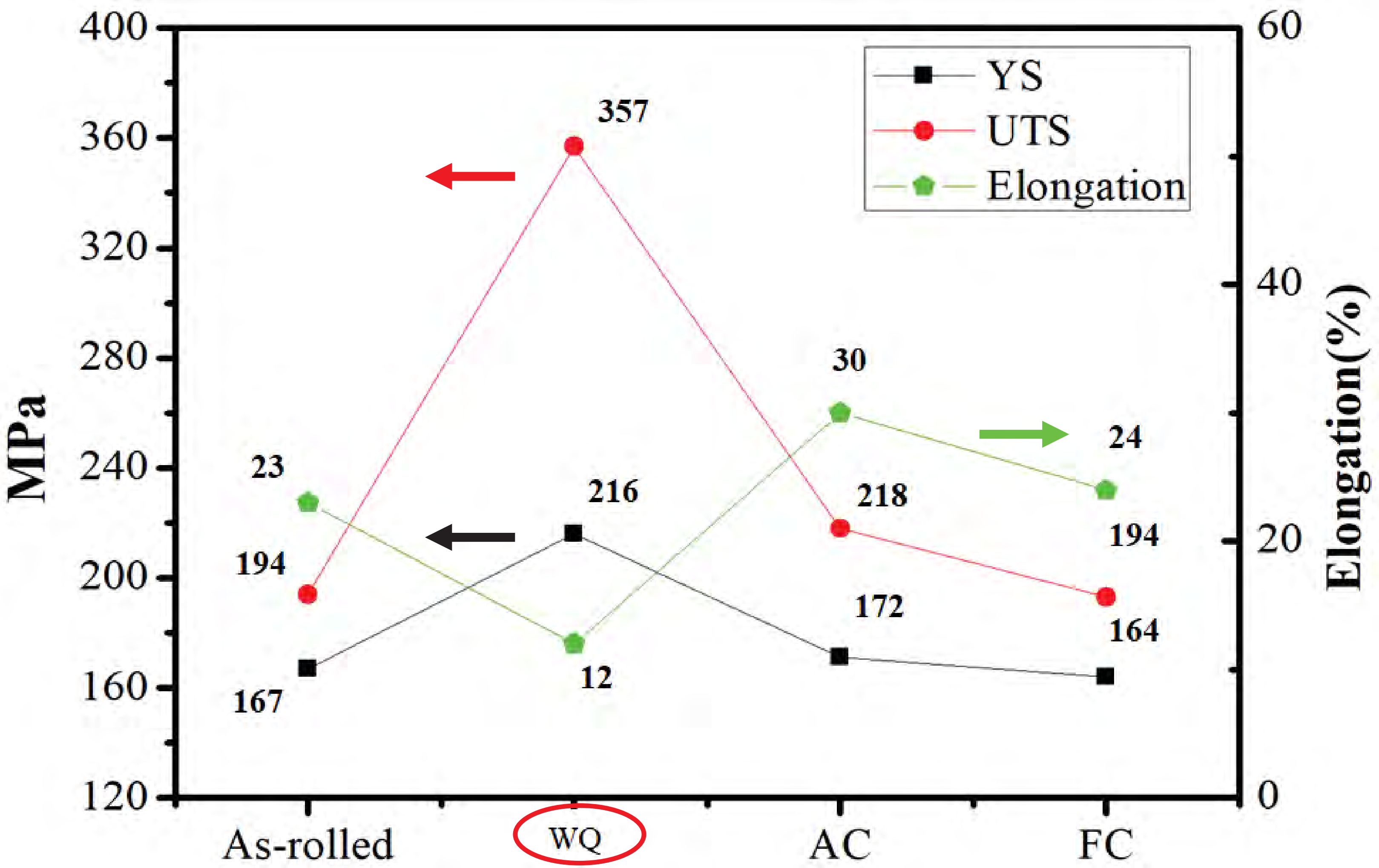
(a-c) is lower magnification and higher magnification (d-f).

Effect of cooling rate on XRD spectra



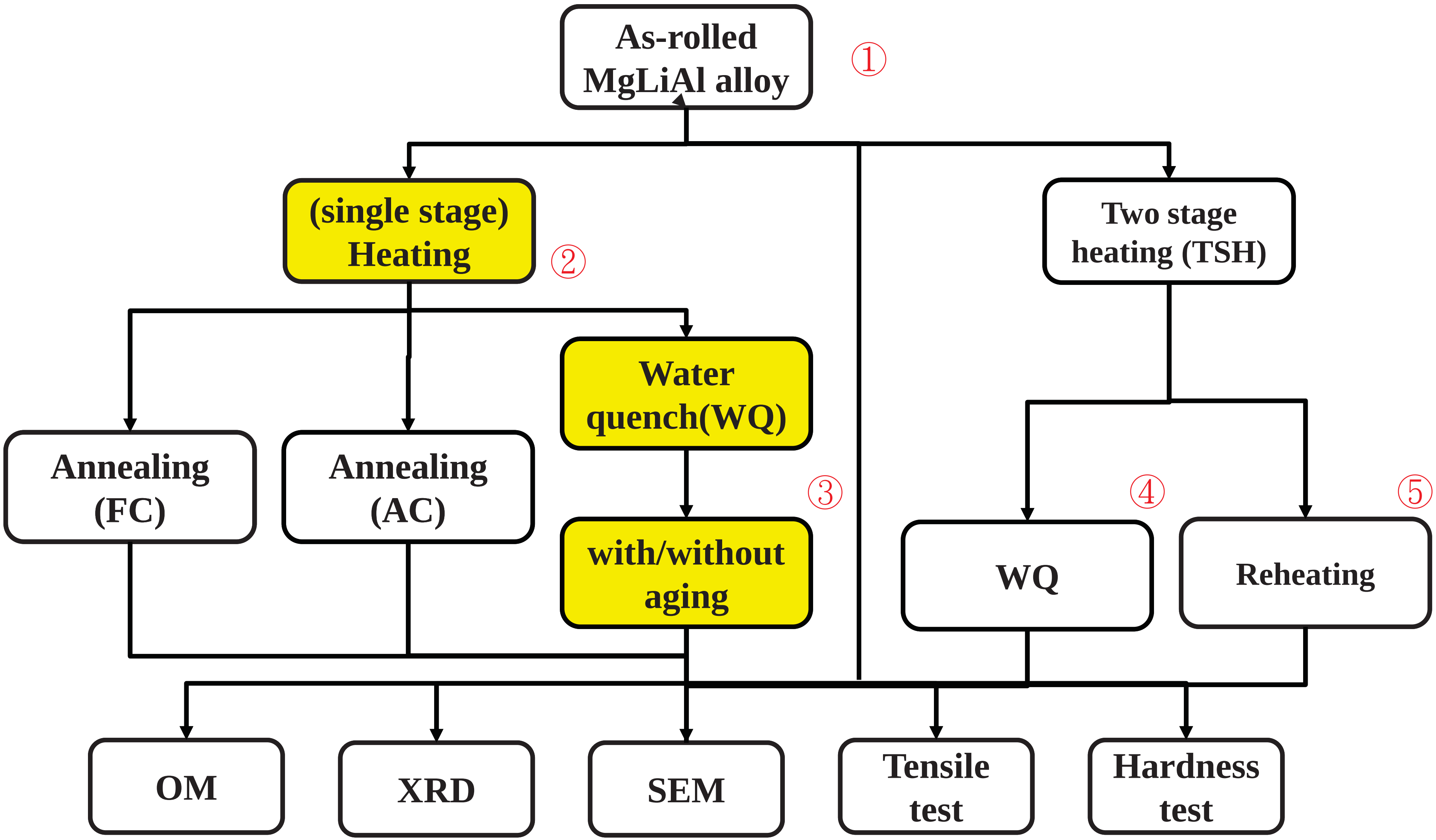
Better mechanical strength with more η from slow cooling rate?

Effect of cooling rate on mechanical property



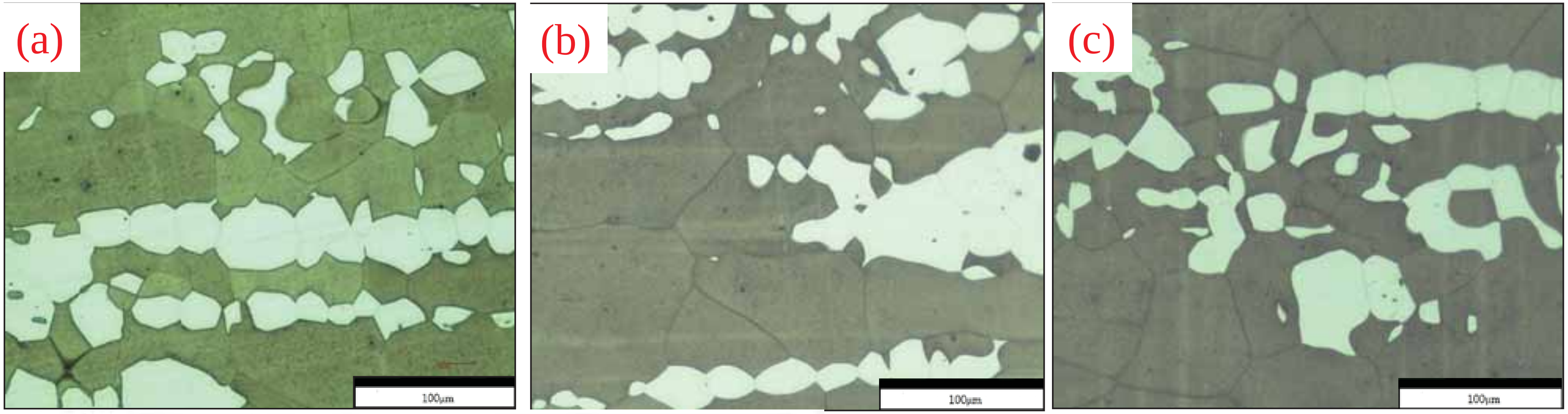
solid solution vs. precipitation?

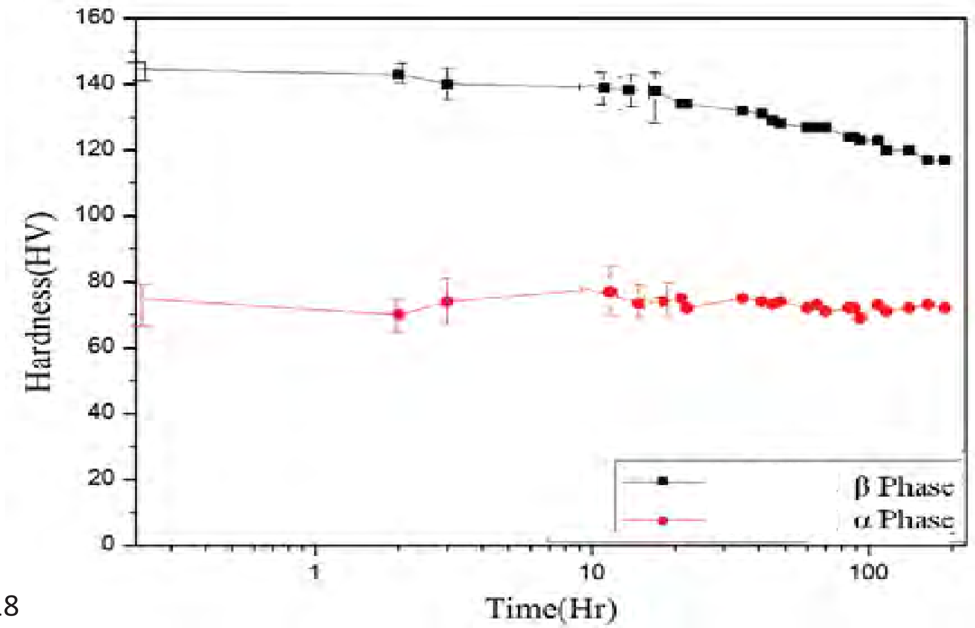
Experimental

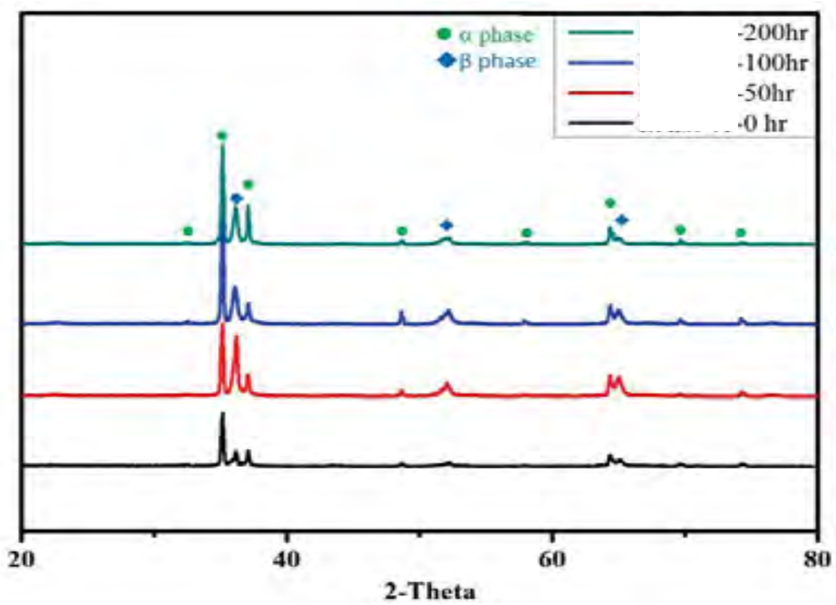


Natural aging of water quenched MgLiAl alloy

aged at room temperature for (a) 0hr, (b) 50hrs and (c)100hrs.

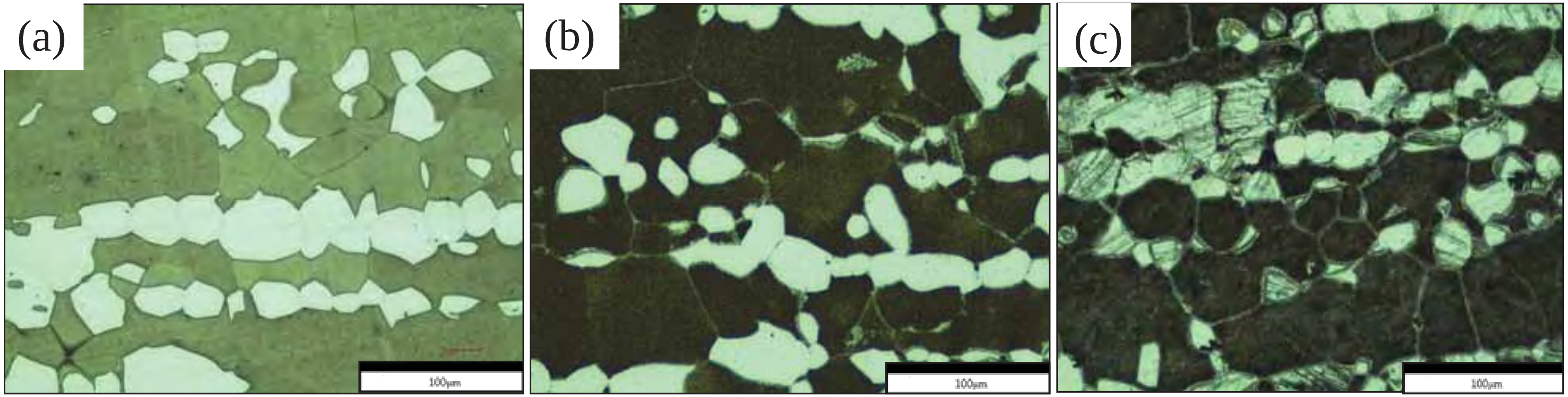






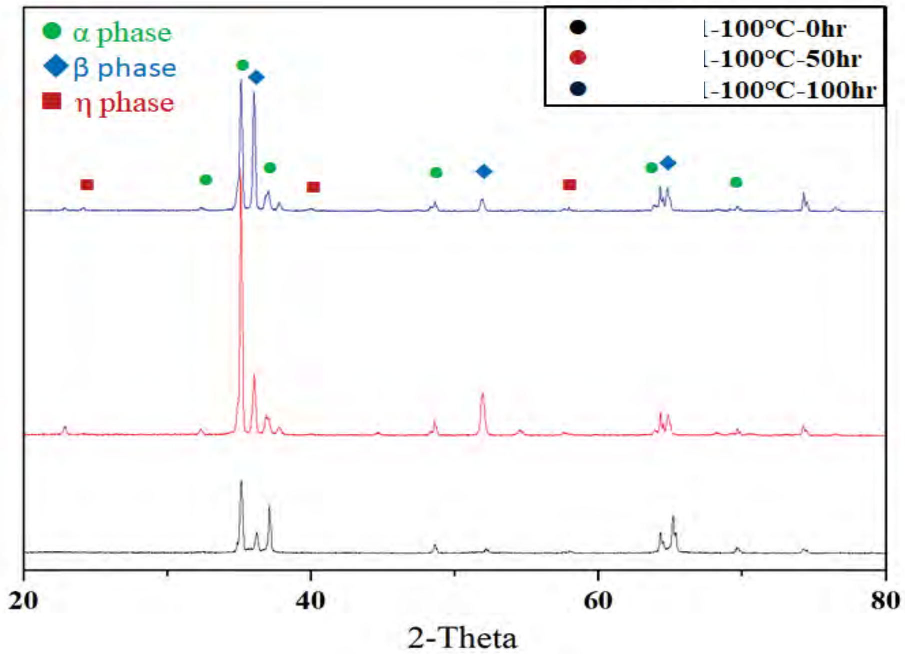
Artificial aging (100℃) of water quenched MgLiAl alloy

aged at 100℃ for (a) 0hr, (b) 50hrs and (c) 100hrs.



(HV)	0hr	50hrs	100hrs
α Phase	78	74	72
β Phase	145	76	77

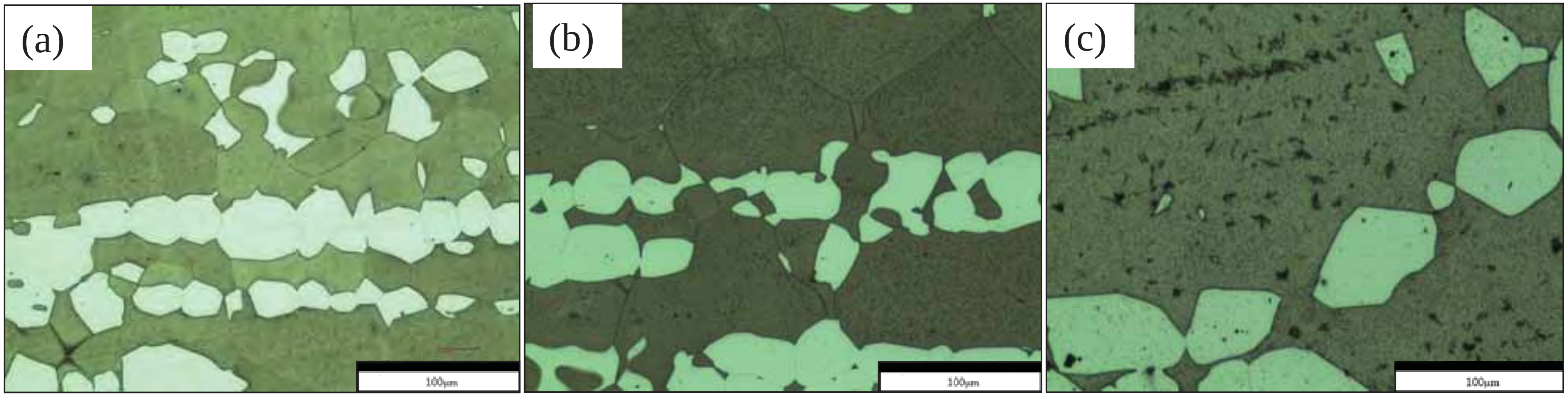
η phase



η precipitation softening

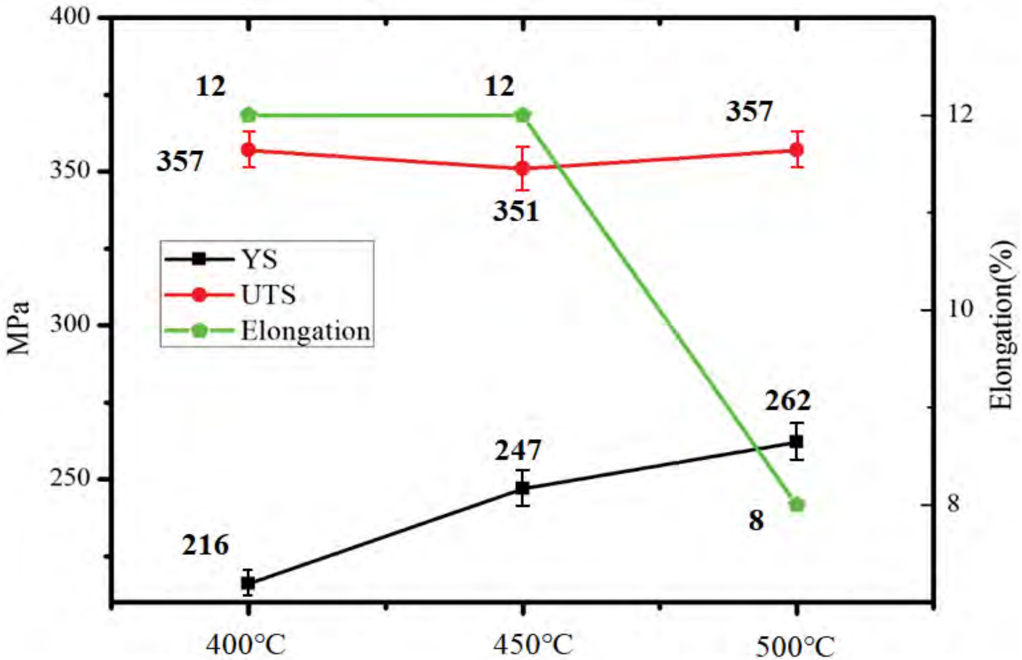
OM of MgLiAl alloy after WQ from different temperatures

(a) WQ from 400℃ (b) WQ from 450℃ (c) WQ from 500℃

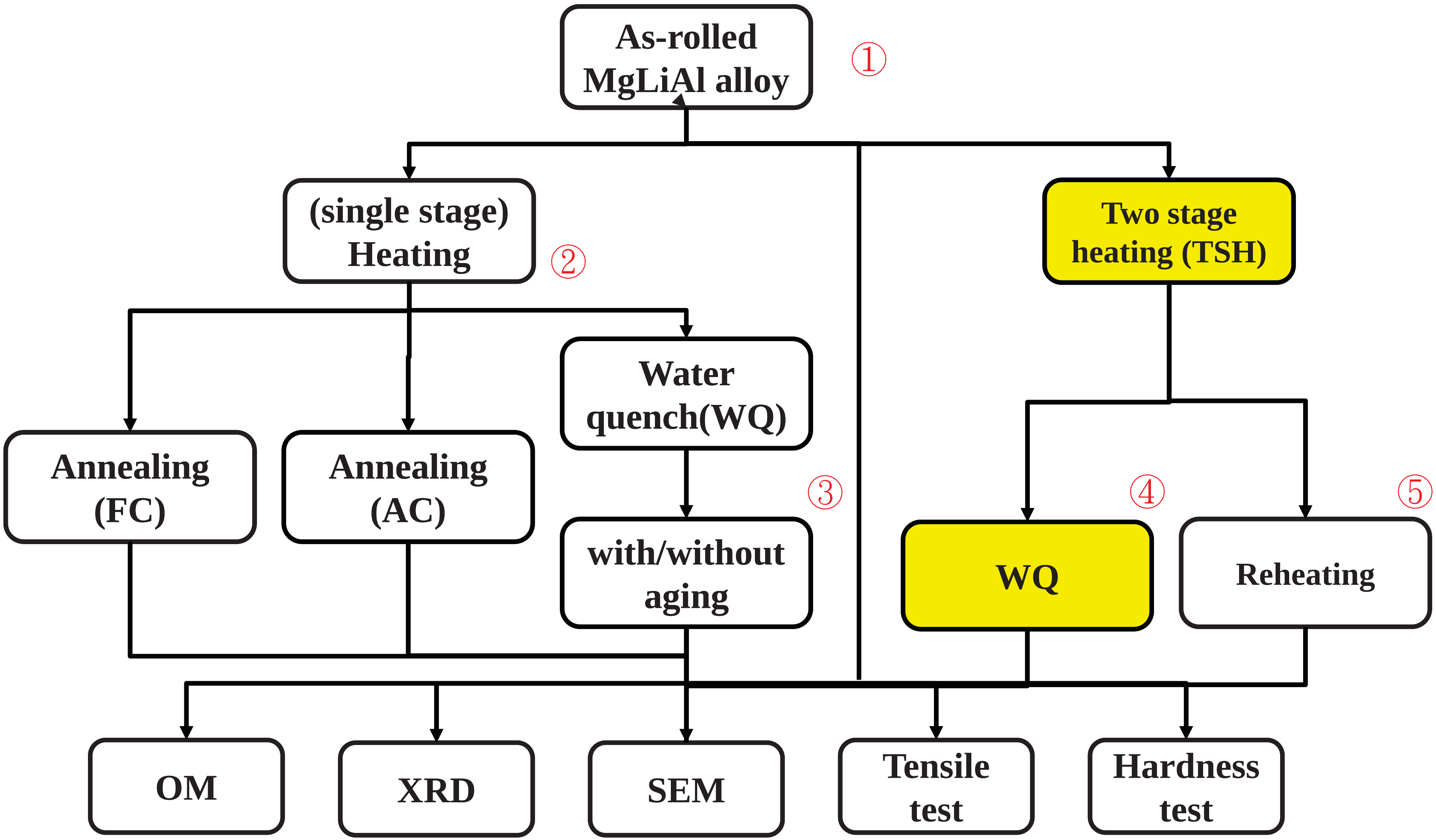


(HV)	400°C	450°C	500°C
α Phase	78	75	76
β Phase	145	142	144

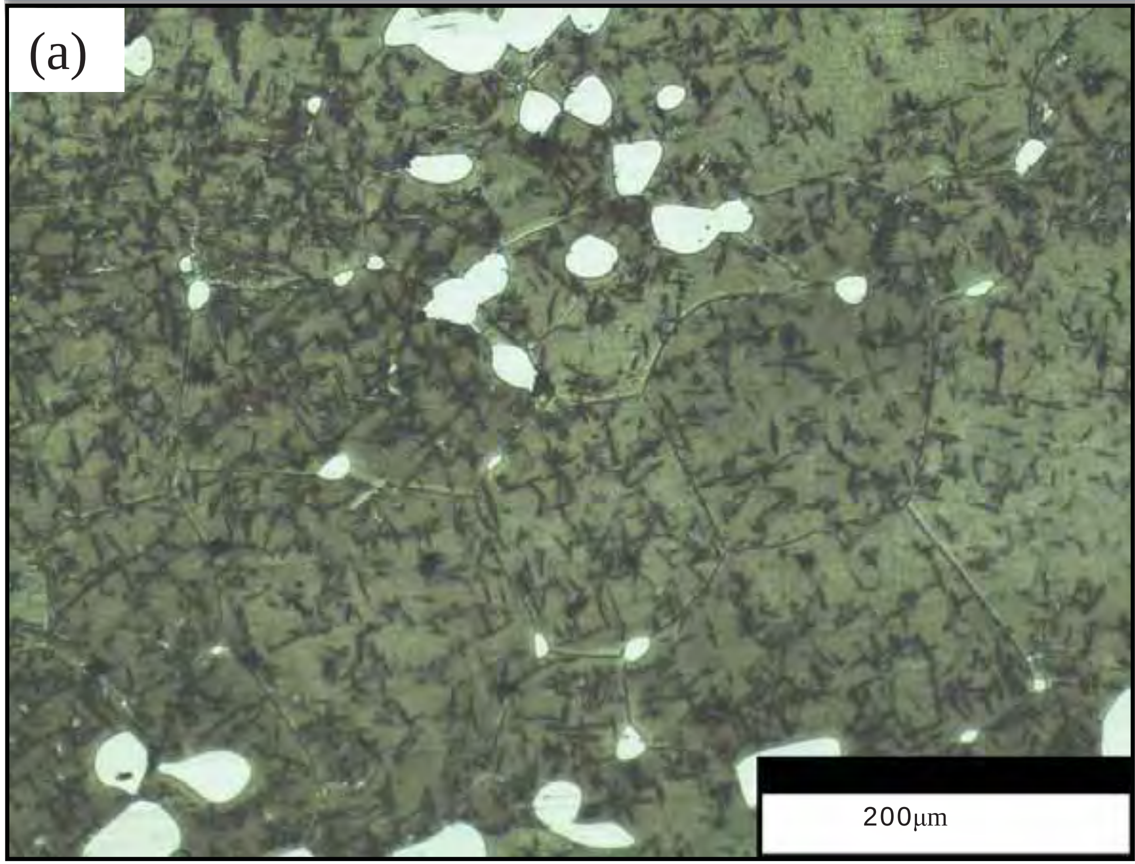
- Hardness is kept
- Grain growth @ 500℃
- Due to stored energy
  - How to remove?

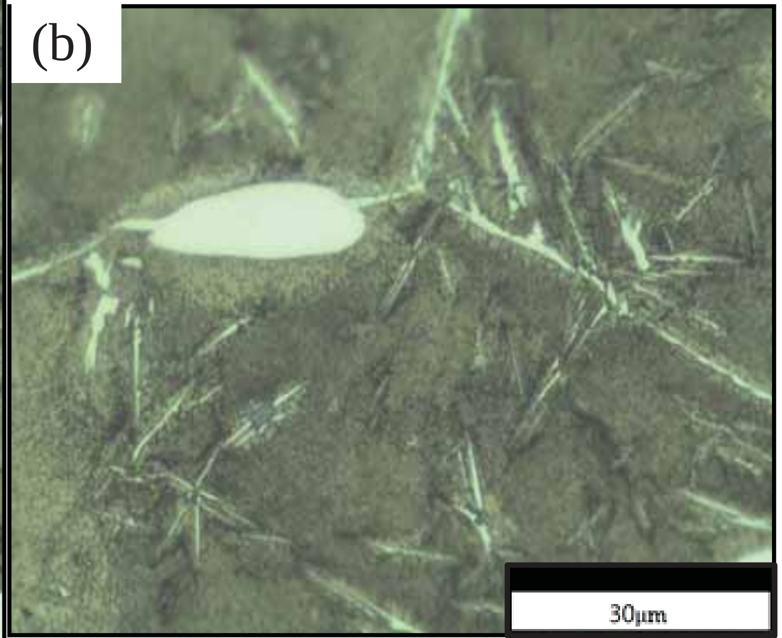


Experimental



OM of MgLiAl alloy after 2-stage heating and then quench

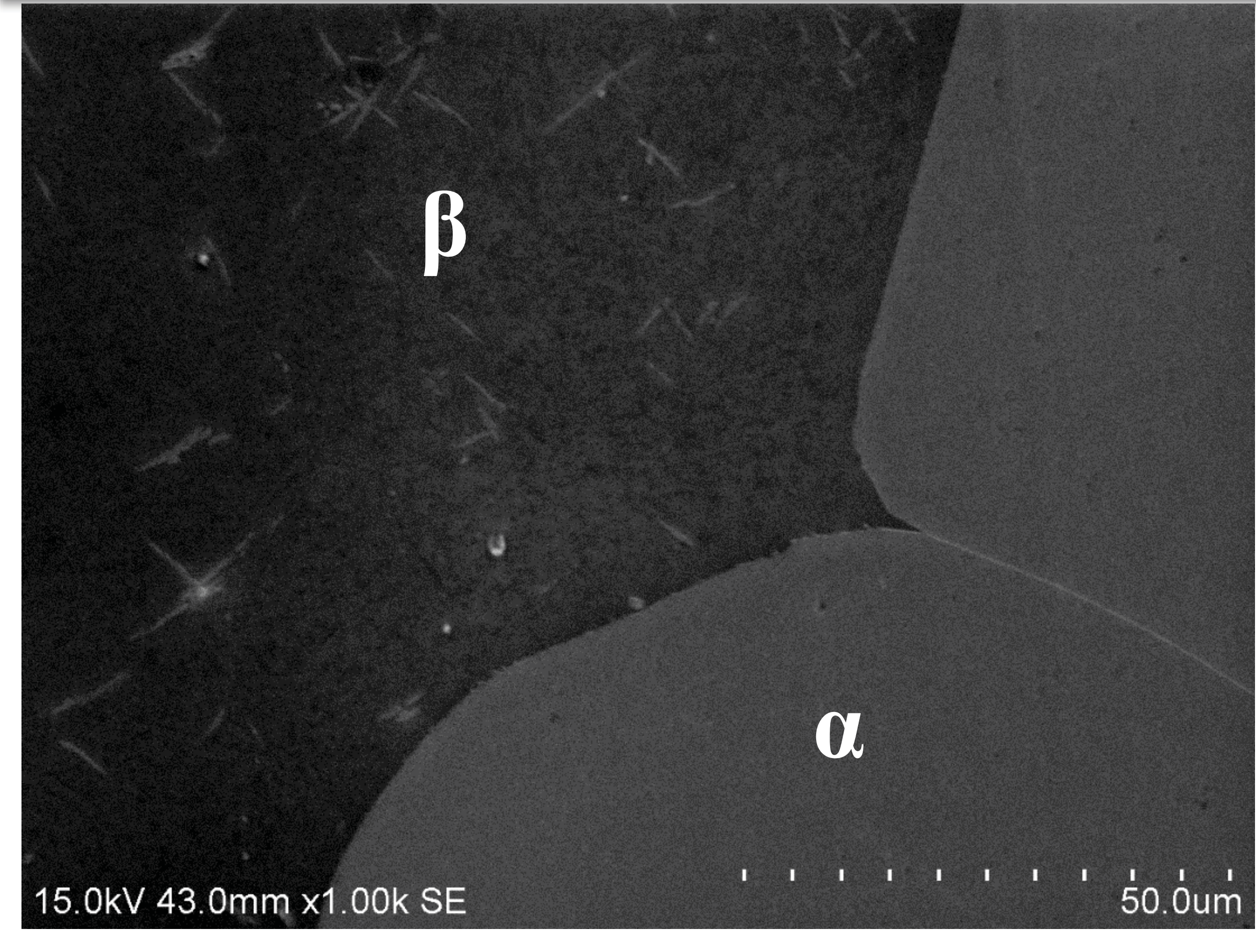




Higher magnification

Heating to 100°C for 1h and then heating to 400°C x 30min

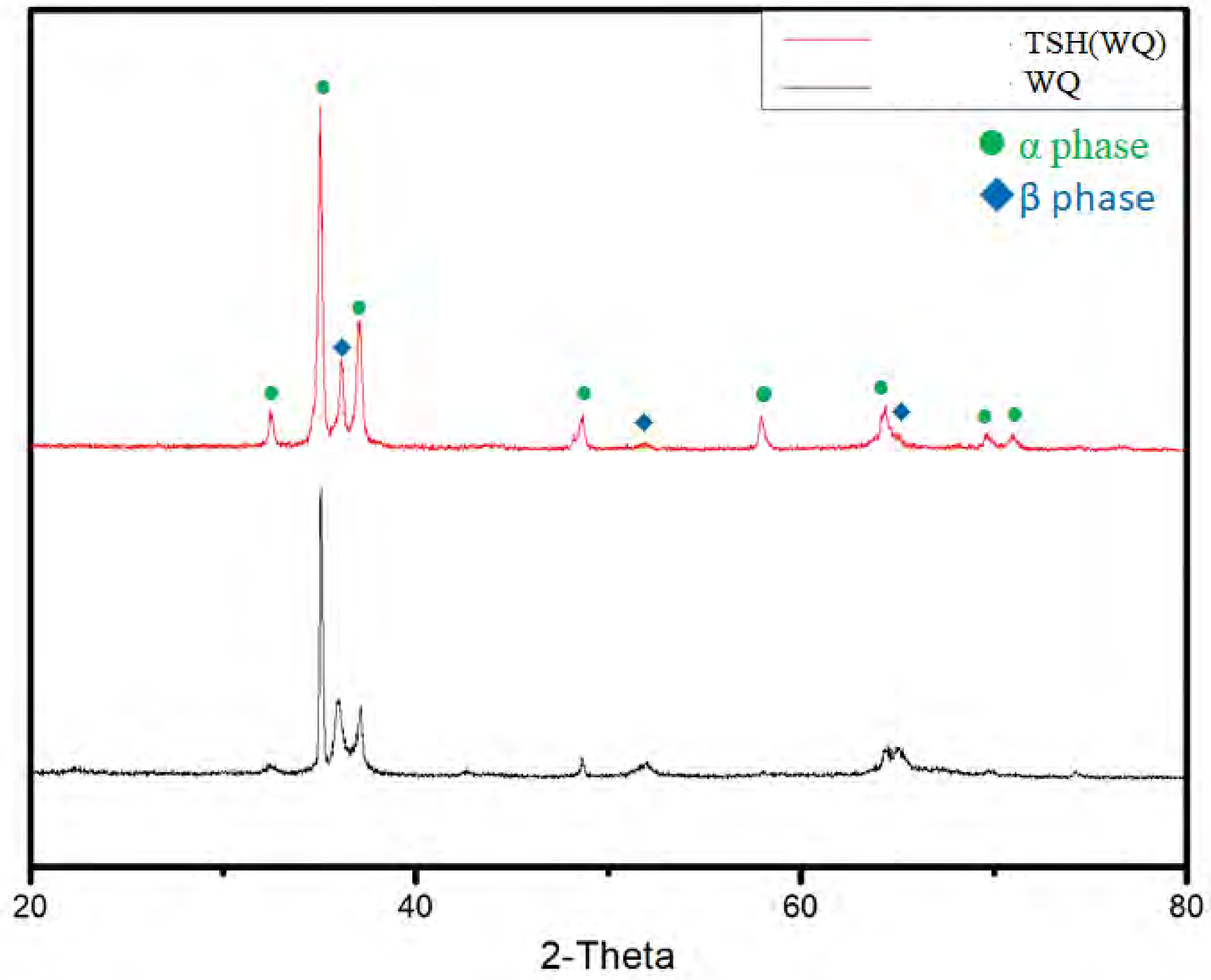
Nanoindentation of MgLiAl alloy after 2-stage heating and then quench



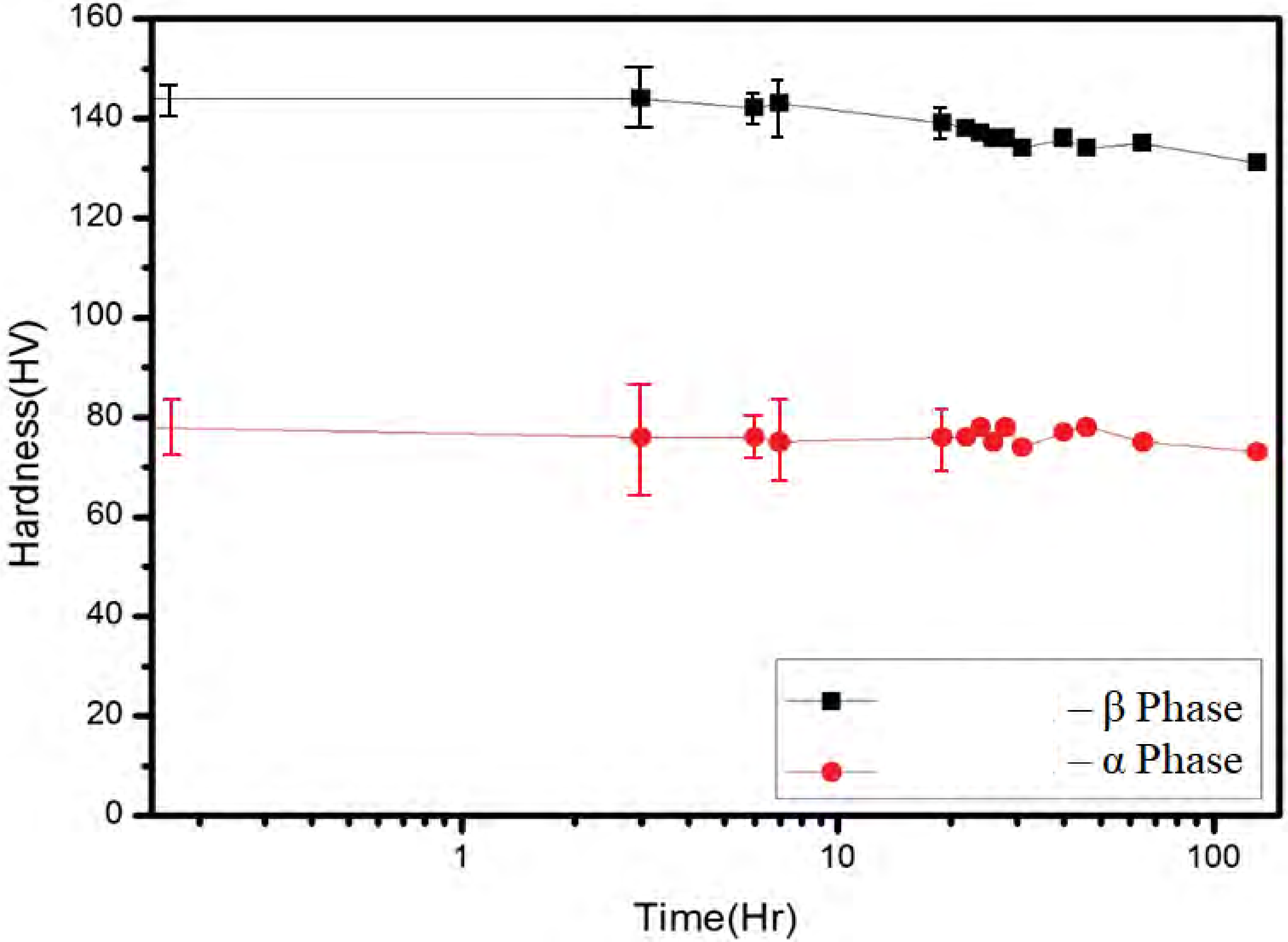
	Young's modulus
α phase	53 ± 5 GPa
β phase	46 ± 6 GPa

Widmanstätten pattern?

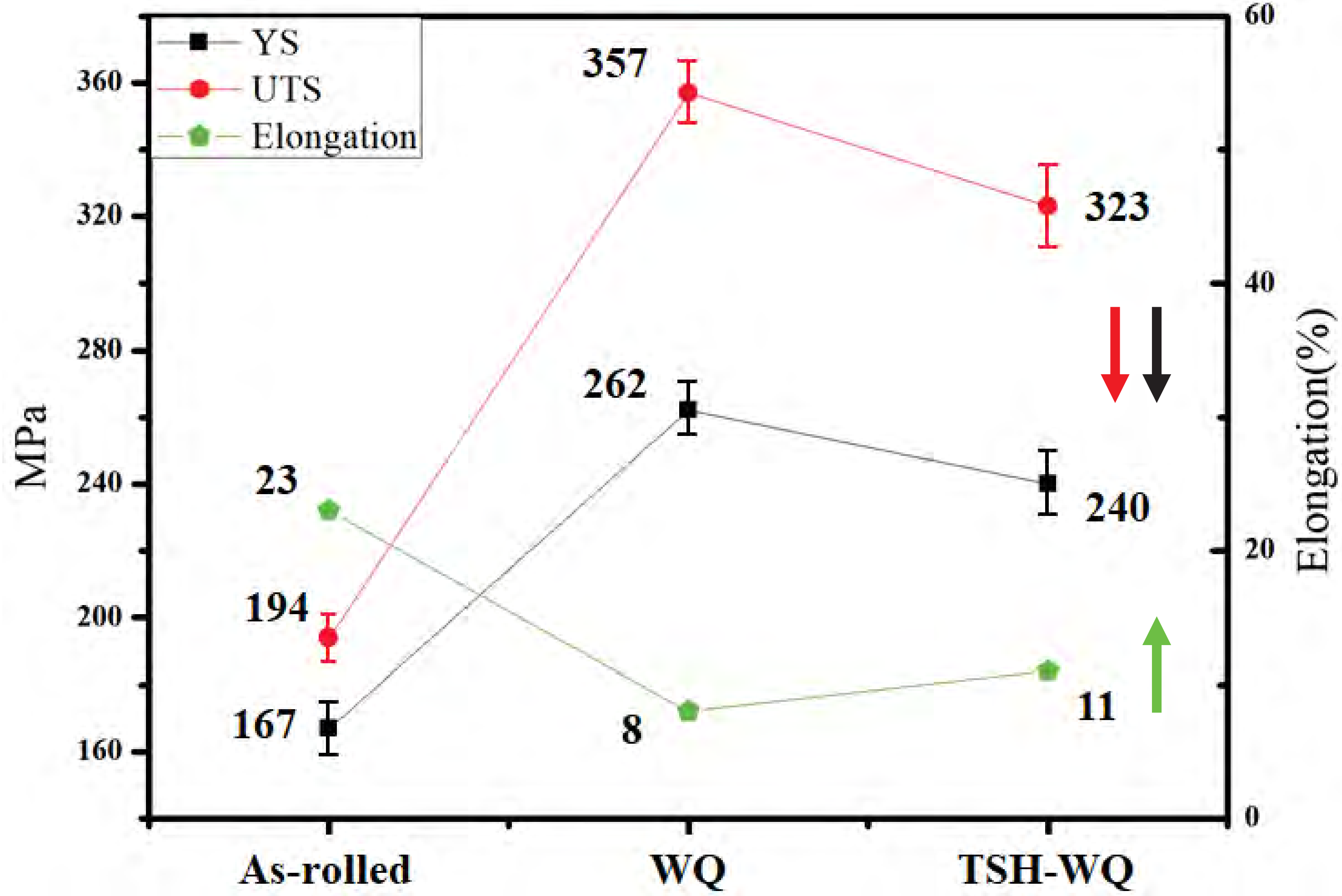
XRD of MgLiAl alloy after 2-stage heating and then quench



Natural aging of 2-stage heating and quenched MgLiAl alloy

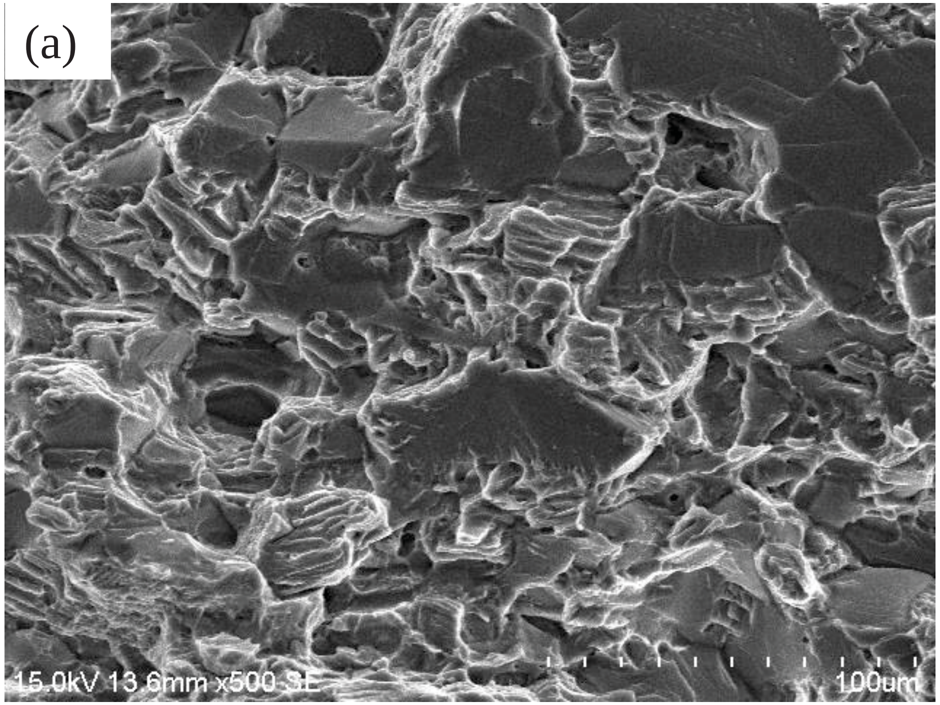


Mechanical property of natural aging of 2-stage heating and quenched MgLiAl alloy



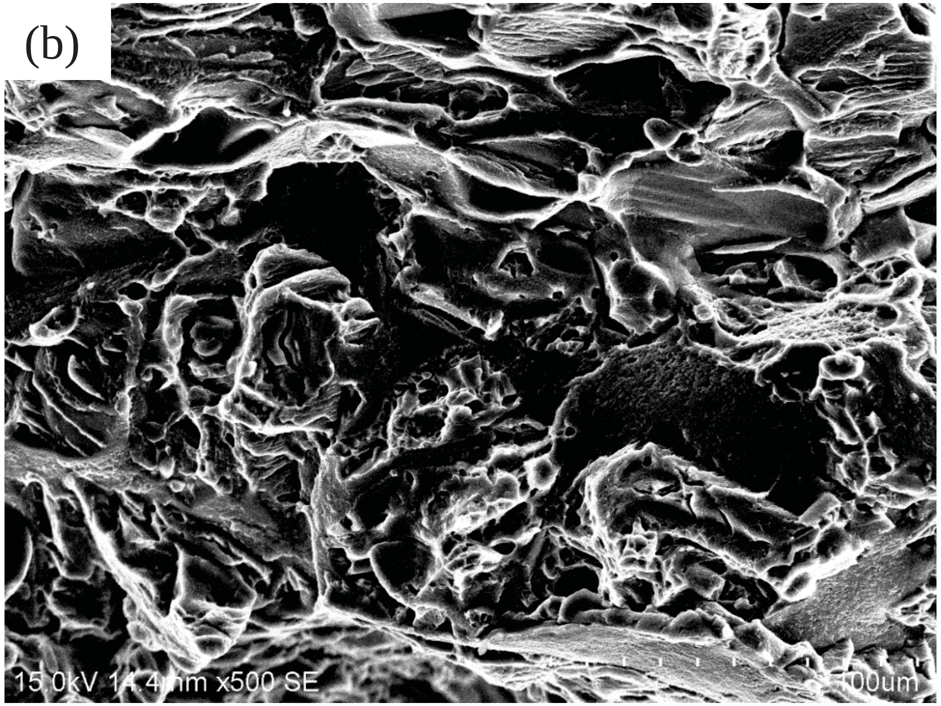
Fracture surfaces of WQ and 2-stage heating and quenched MgLiAl alloy

(a) WQ



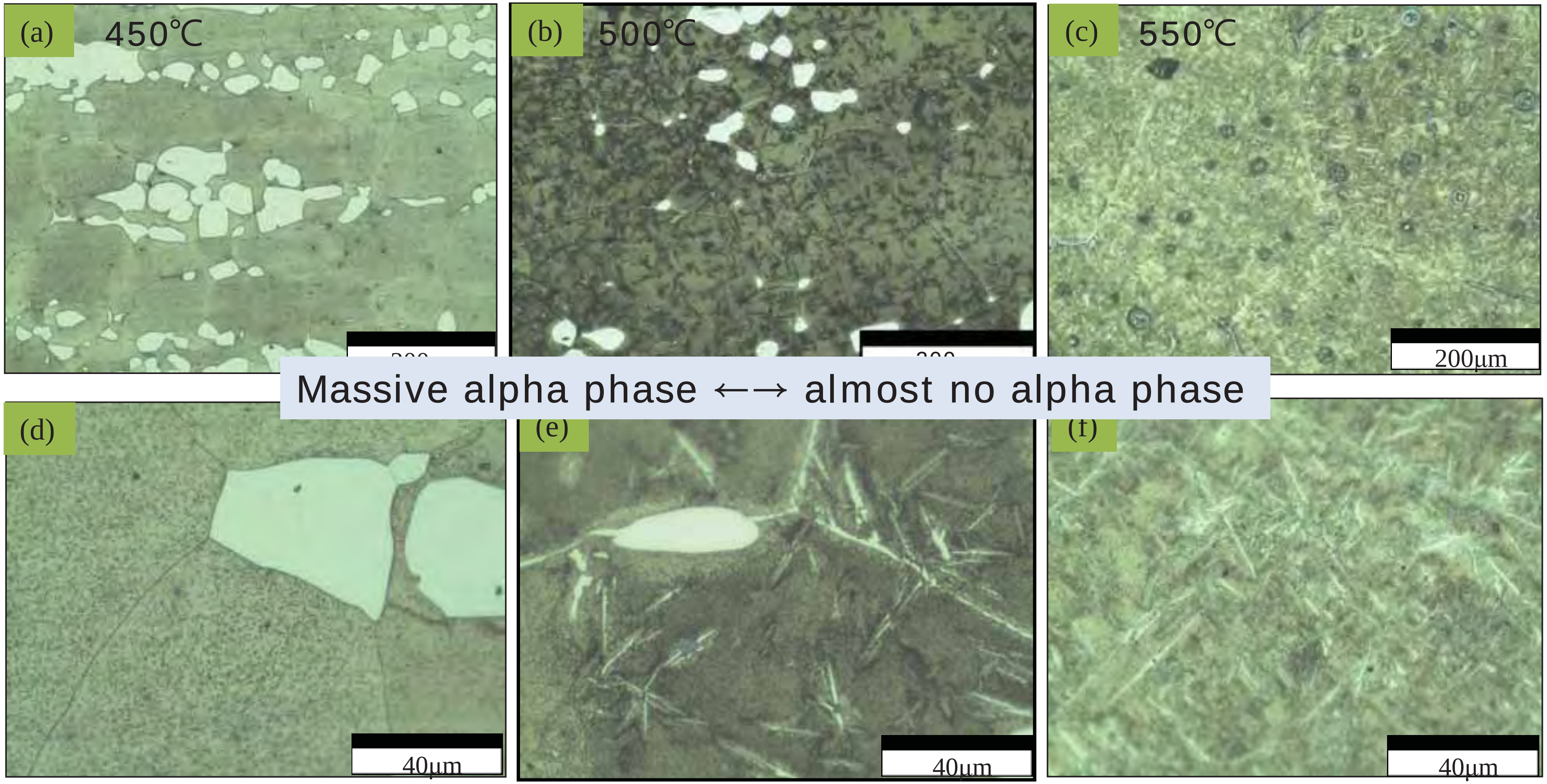
Cleavage-like (brittle)

(b) TSH(WQ)



Dimple-like (ductile)

OM of MgLiAl alloy WQ from different temperatures in 2-stage heating

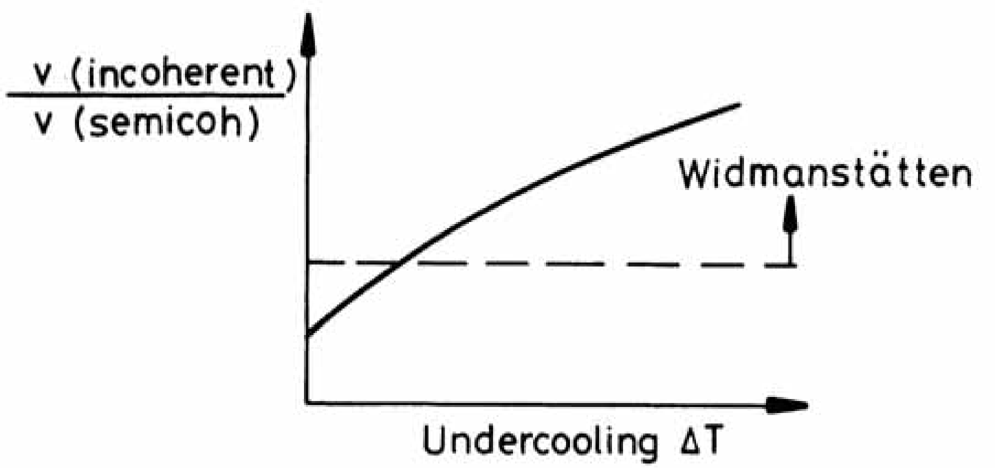


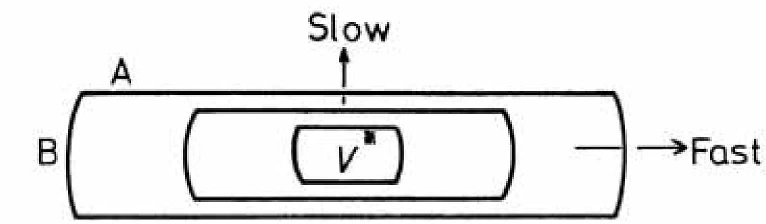
Massive alpha phase ←→ almost no alpha phase

(HV)	450°C	500°C	550°C
α Phase	76	78	-
β Phase	141	145	148

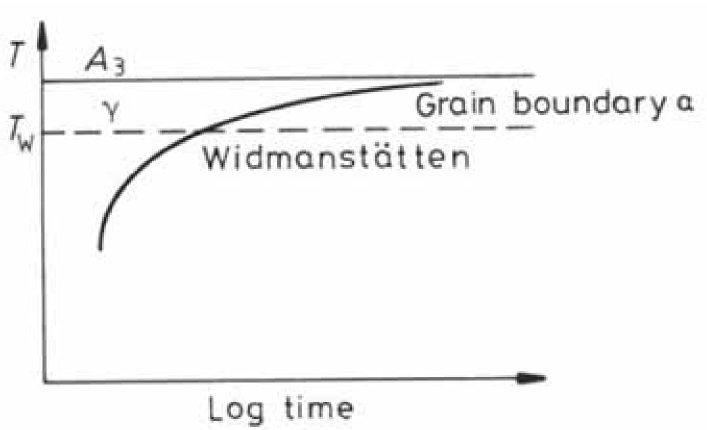
Widmanstätten pattern?

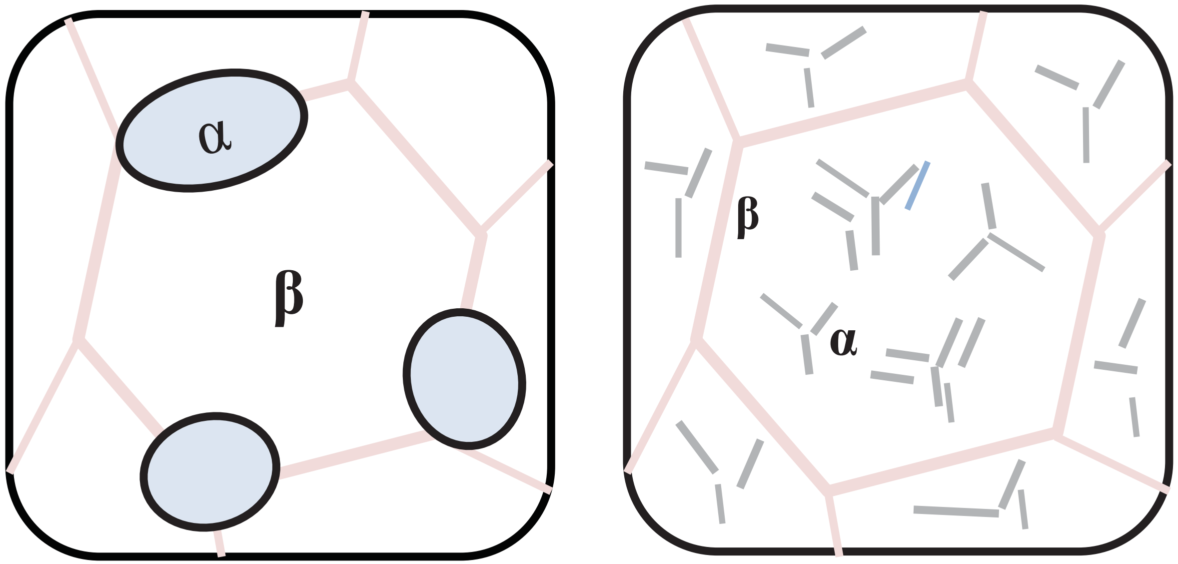
WIDMANSTÄTTEN structures





(A) Low-mobility semicoherent interfaces.
(B) High-mobility incoherent interfaces

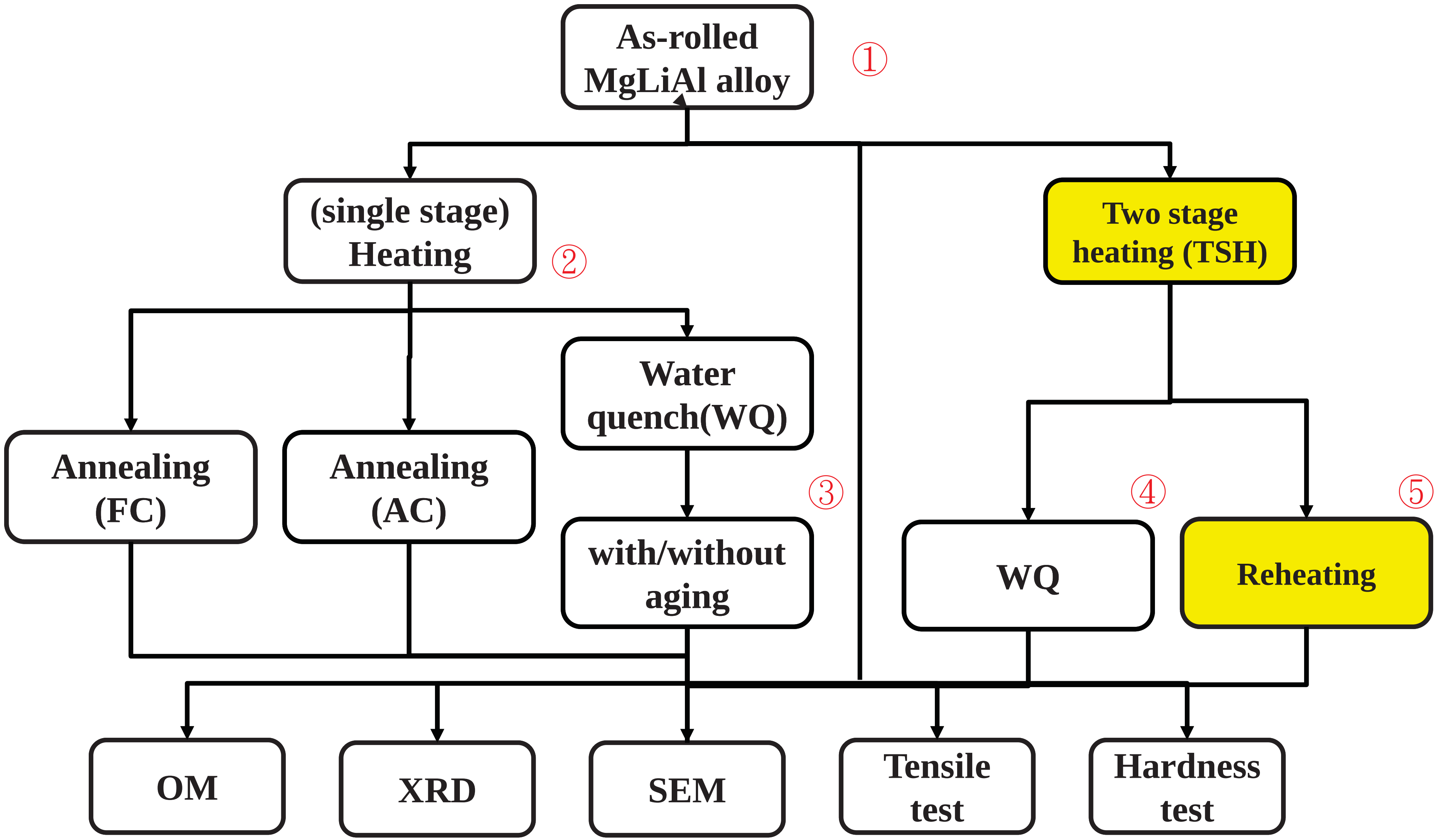




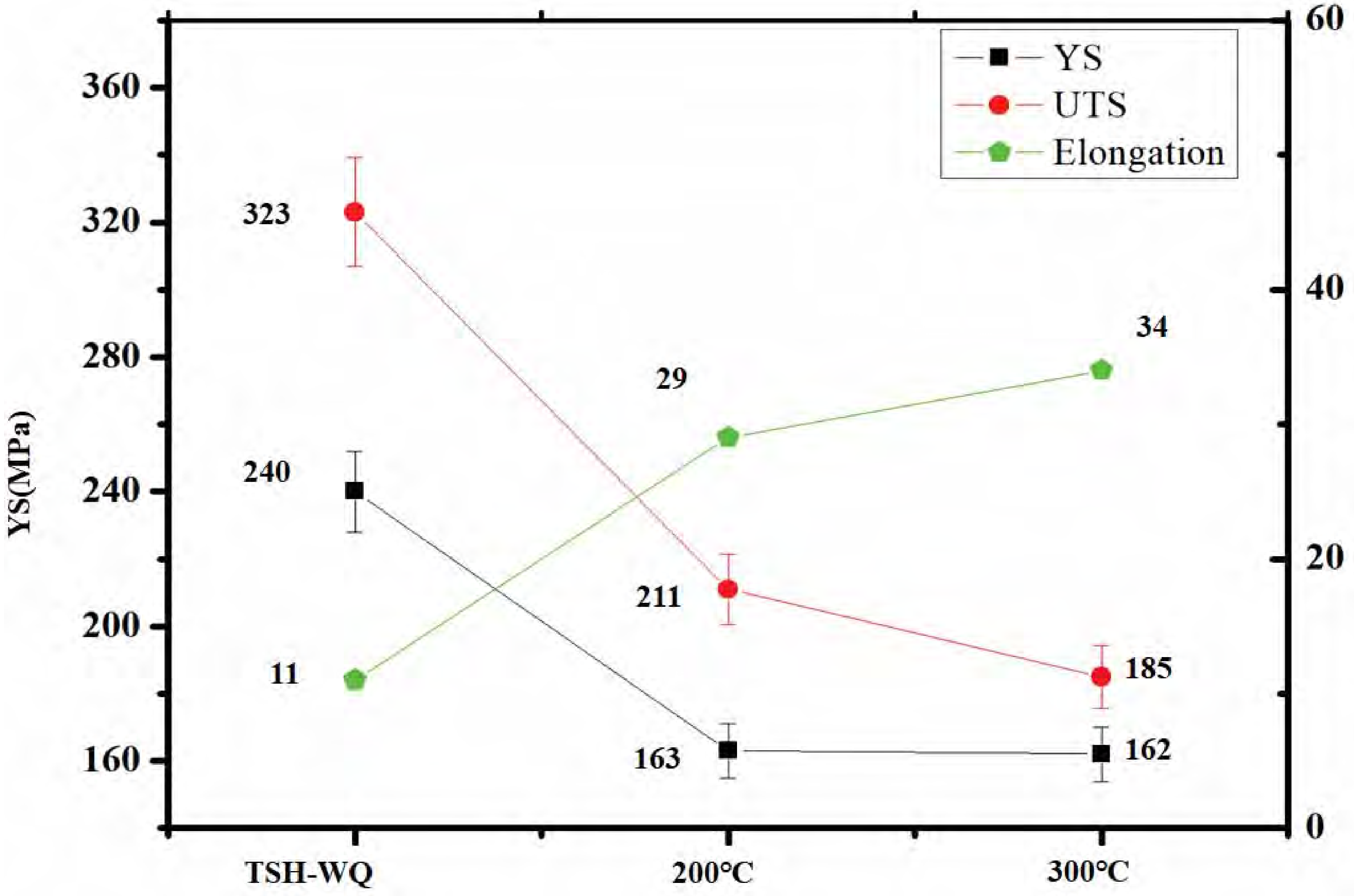
Slow cooling Rapid cooling

Porter, D. A., et al. (2009). *Phase Transformations in Metals and Alloys, (Revised Reprint)*, CRC press.

Experimental



Mechanical property of reheated MgLiAl alloy after 2-stage heating and quench



Summary

- Compared to commercial LZ91, the MgLiAl alloy
  - has doubled UTS (183 → 357 MPa)
  - with reasonable elongation (8%)
- Aging softening
  - Solid solution strengthening is more prominent than precipitation strengthening.
- Under higher solid solution temperature
  - Water quenching leads to Widmanstätten pattern.
- TSH + WQ vs. WQ
  - The former has slightly reduced strength, but improved elongation.
- Reheating after TSH + WQ
  - The elongation can be greatly improved with strength sacrificed.

Thanks for your attention

Thanks for your attention