Microstructure-Property Relationships in AlMgCu Alloys

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Outline

- Background
  - requirements of Al alloys for automotive closure panel and structural applications
  - recap of some previous work on alloys within this system
    - ➔effect of Mg & Cu levels on properties and ageing behaviour
    - ➔recovery behaviour
- Brief Summary of Properties
- Characterisation of Precipitation Processes
- Potential Benefits & Applications

Background

- Aluminium in automotive applications:
  - some requirements are:
    - good formability
    - stability in storage (limited natural ageing)
    - in-service strength (response to automotive paint bake cycle)
    - acceptable appearance for outer panels (freedom from roping and Lüdering)
  - Al-Mg-Si-(Cu) (6xxx) alloys used for closure panel applications (inners/outers)
  - Al-Mg (5xxx) and Al-Mg-Si-(Cu) (6xxx) alloys used for structural applications.

- Published work (eg, Ratchev et al., NKK Corp.) has shown that age hardening in the Al-Mg-Cu system may make such alloys suitable for automotive applications.
  - in general, 5xxx alloys have better formability than 6xxx alloys
  - 1.5-5.5 wt.% Mg, 0.3-1.0 wt.% Cu (ie, low Cu:Mg ratio)
  - strength retention during paint bake (precipitation ‘offsets’ recovery)

Previous Work

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Alloy	Mg	Cu	Fe	Mn	Si
Al-3Mg-0.2Cu	2.9	0.20	0.21	0.25	0.12
Al-3Mg-0.3Cu	2.9	0.29	0.20	0.25	0.12
Al-3Mg-0.4Cu	3.0	0.42	0.21	0.25	0.12
Al-3Mg-0.5Cu	3.0	0.50	0.11	0.25	0.12
Al-3Mg-0.6Cu	3.0	0.57	0.21	0.25	0.12
Al-4Mg-0.5Cu	4.0	0.51	0.21	0.24	0.13

- Alloys lab cast and hot and cold rolled to 1mm thick sheet
- Solution heat treated at 550°C + Forced Air Quench
- Ageing temperatures of 140-200˚C
- Recovery experiments: pre-strains of 5-15%, followed by ageing at 140-180˚C

Tensile Properties & Bendability *

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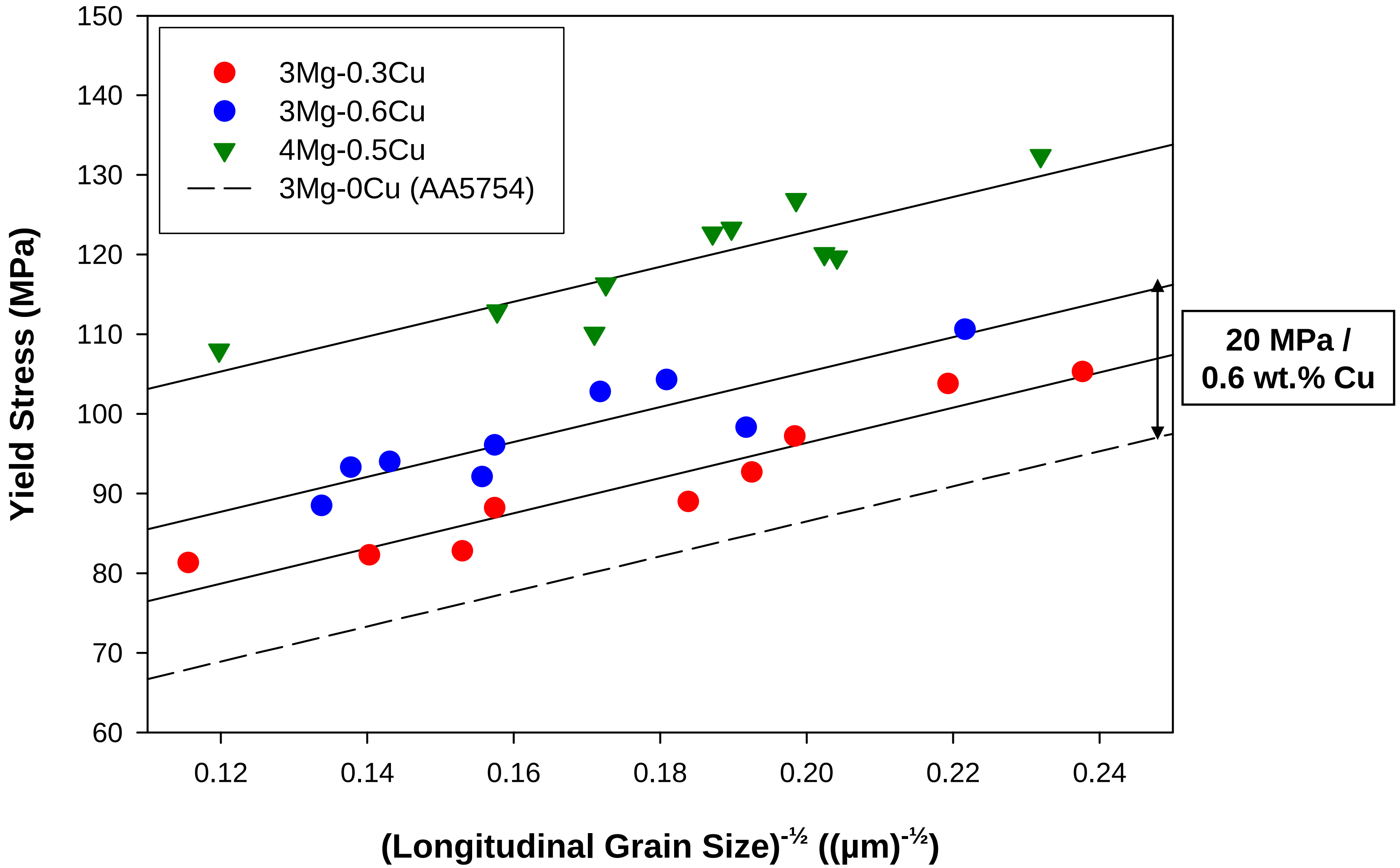
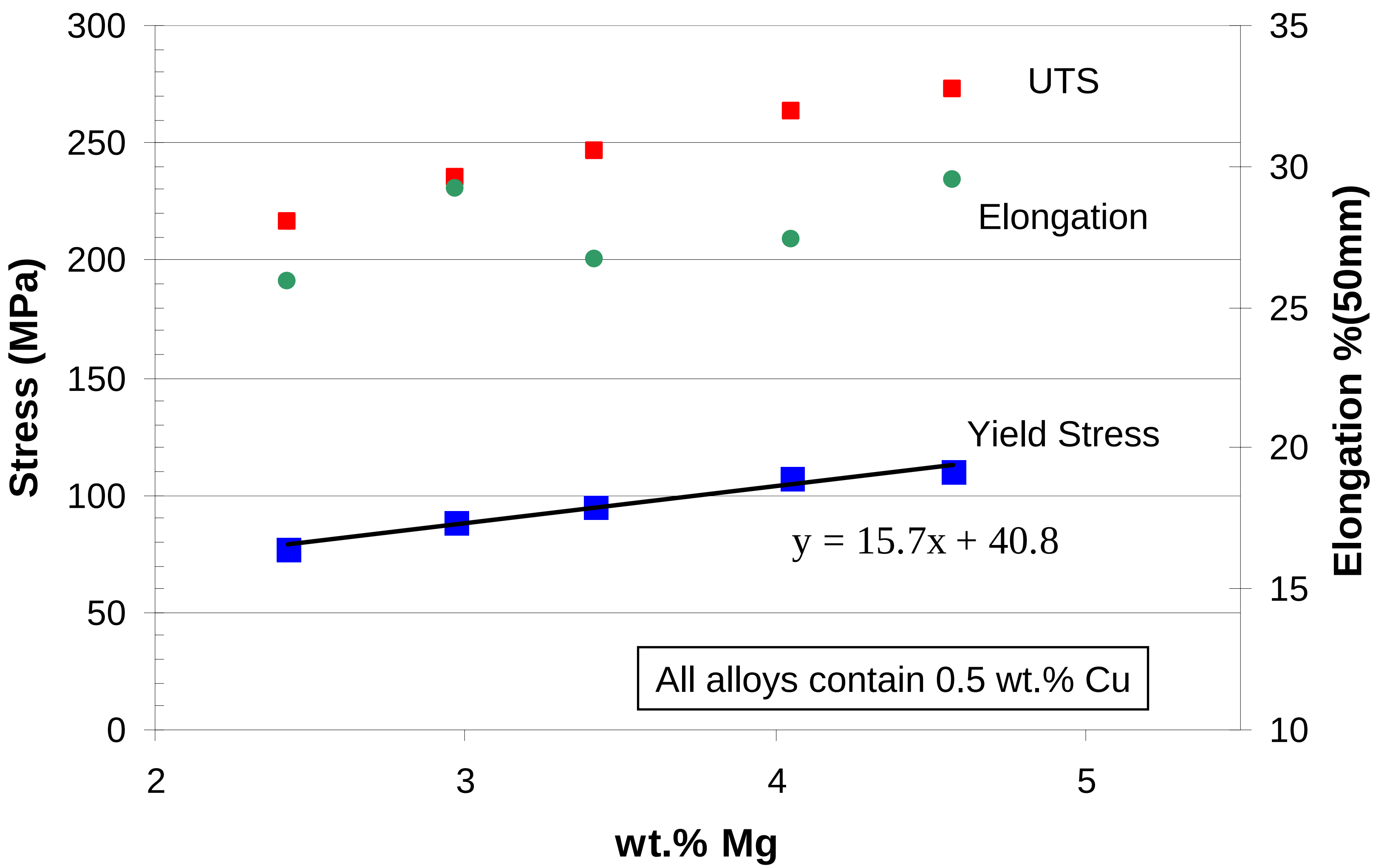
Alloy	Yield Stress (MPa)	UTS (MPa)	Total Elongation (%)	Bendability ($r_{min.}$/t)	Reduction in Area (%)
Al-3Mg-0.2Cu	89	227	24.5	0	70
Al-3Mg-0.3Cu	92	231	24.7	0	71
Al-3Mg-0.4Cu	94	239	28.3	0	67
Al-3Mg-0.5Cu	88	235	29.2	0	----
Al-3Mg-0.6Cu	95	244	23.6	0	62
Al-4Mg-0.5Cu	112	275	28.2	0.18	63

* Properties in SHT + Quenched + Naturally Aged for 1 Week Condition

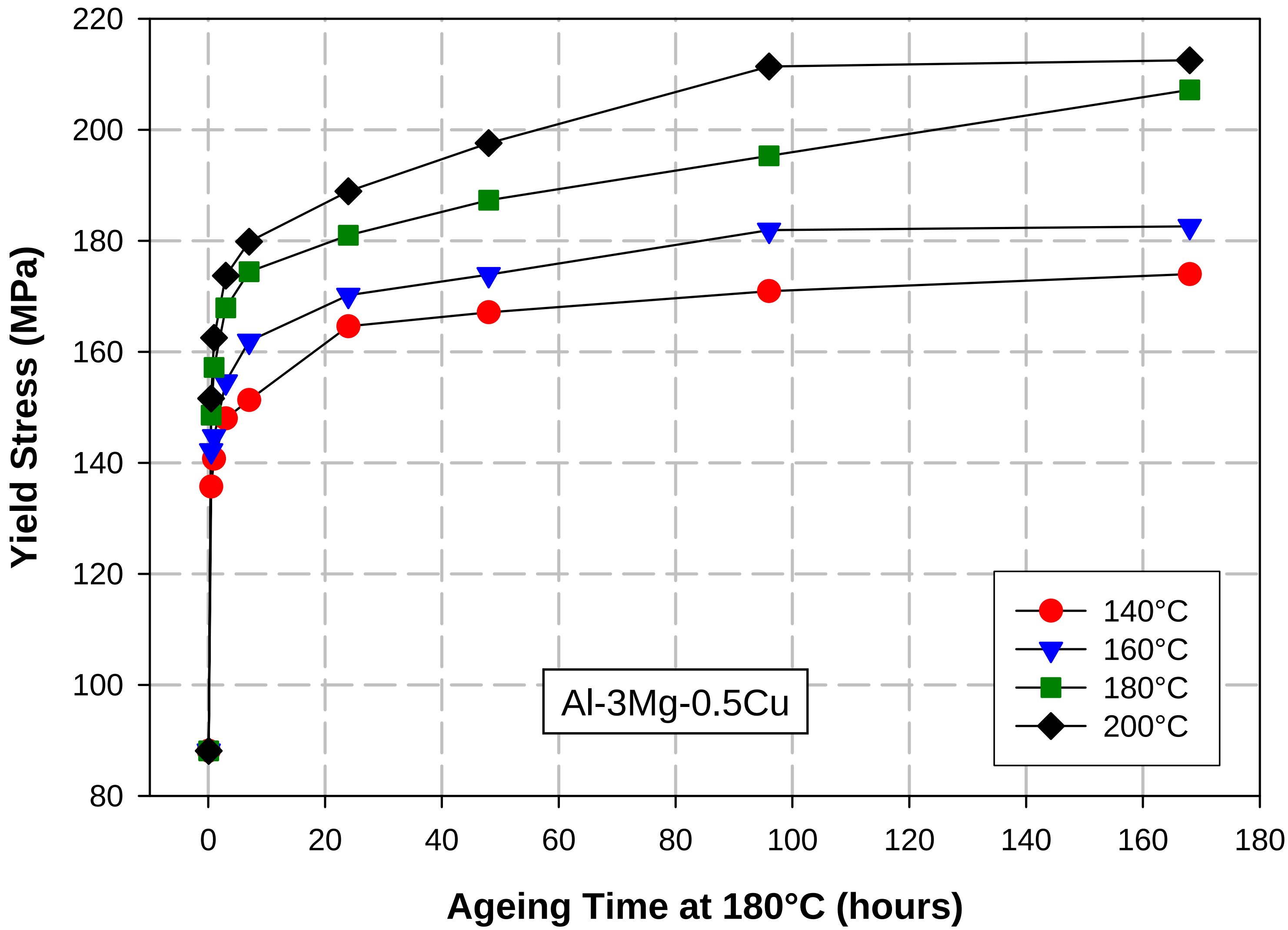
Effect of Grain Size on Yield Stress



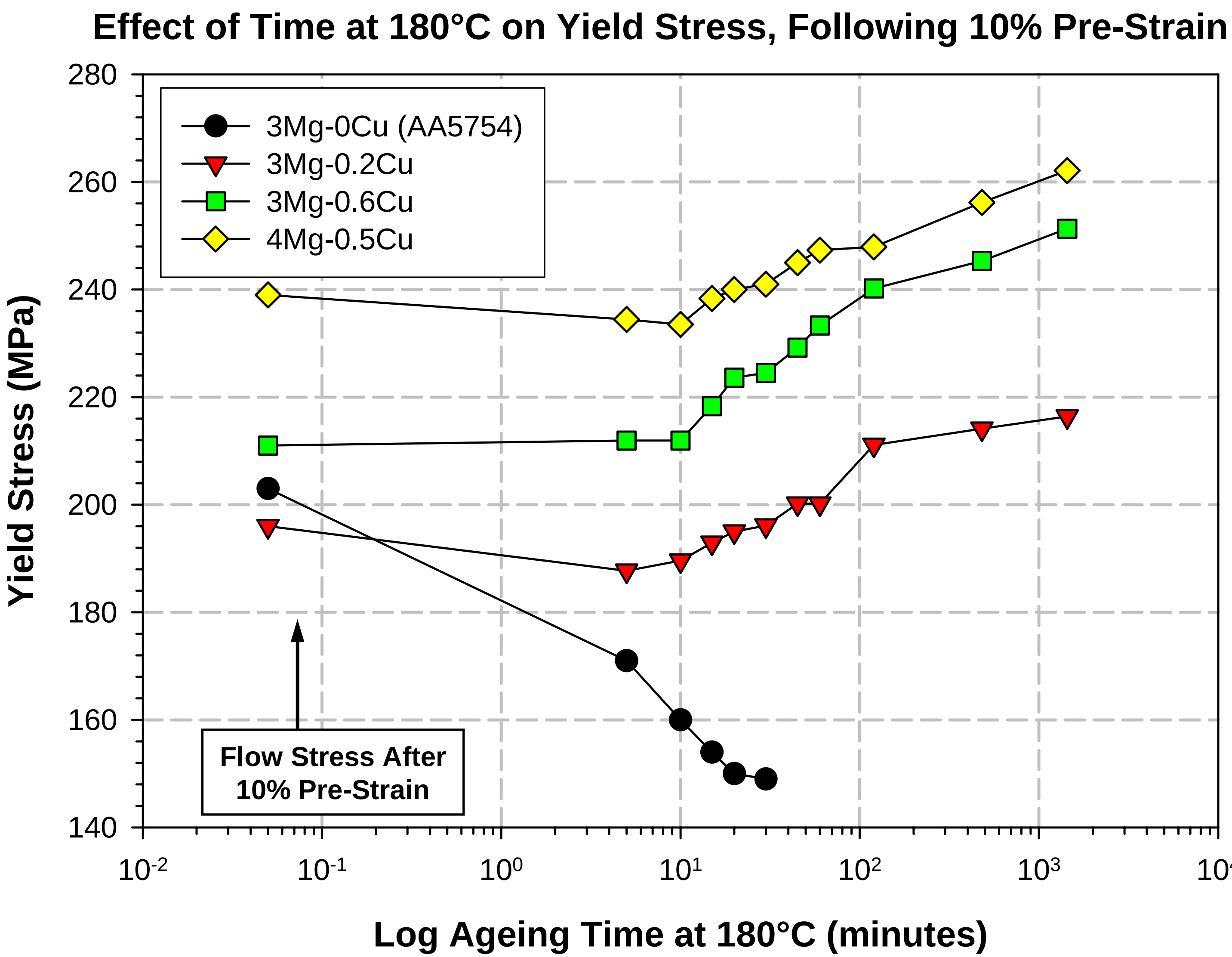
Effect of Mg on Tensile Properties



Effect of Ageing Temperature on YS



Concurrent Recovery/Precipitation in AlMgCu Alloys



More Recent Work

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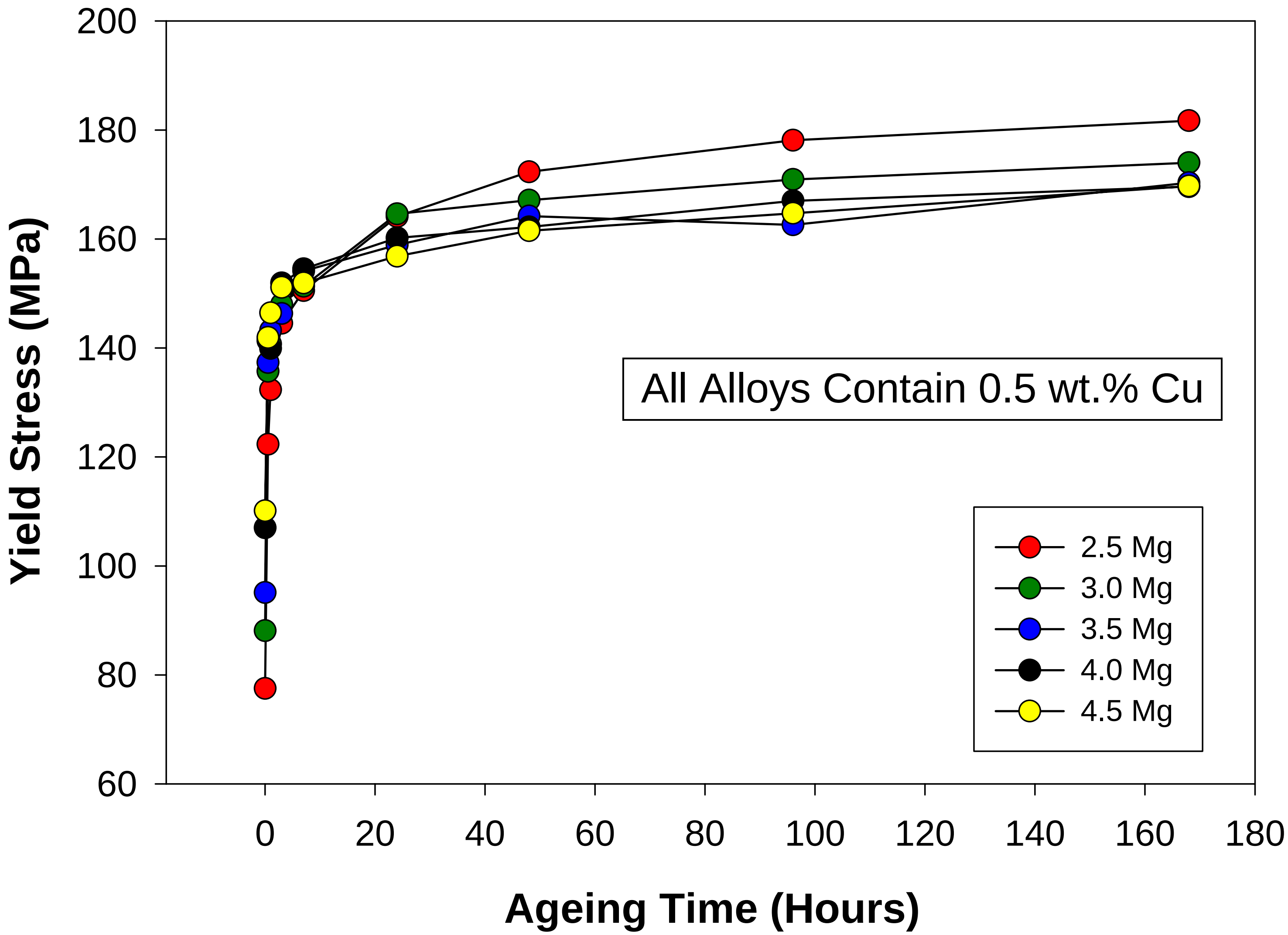
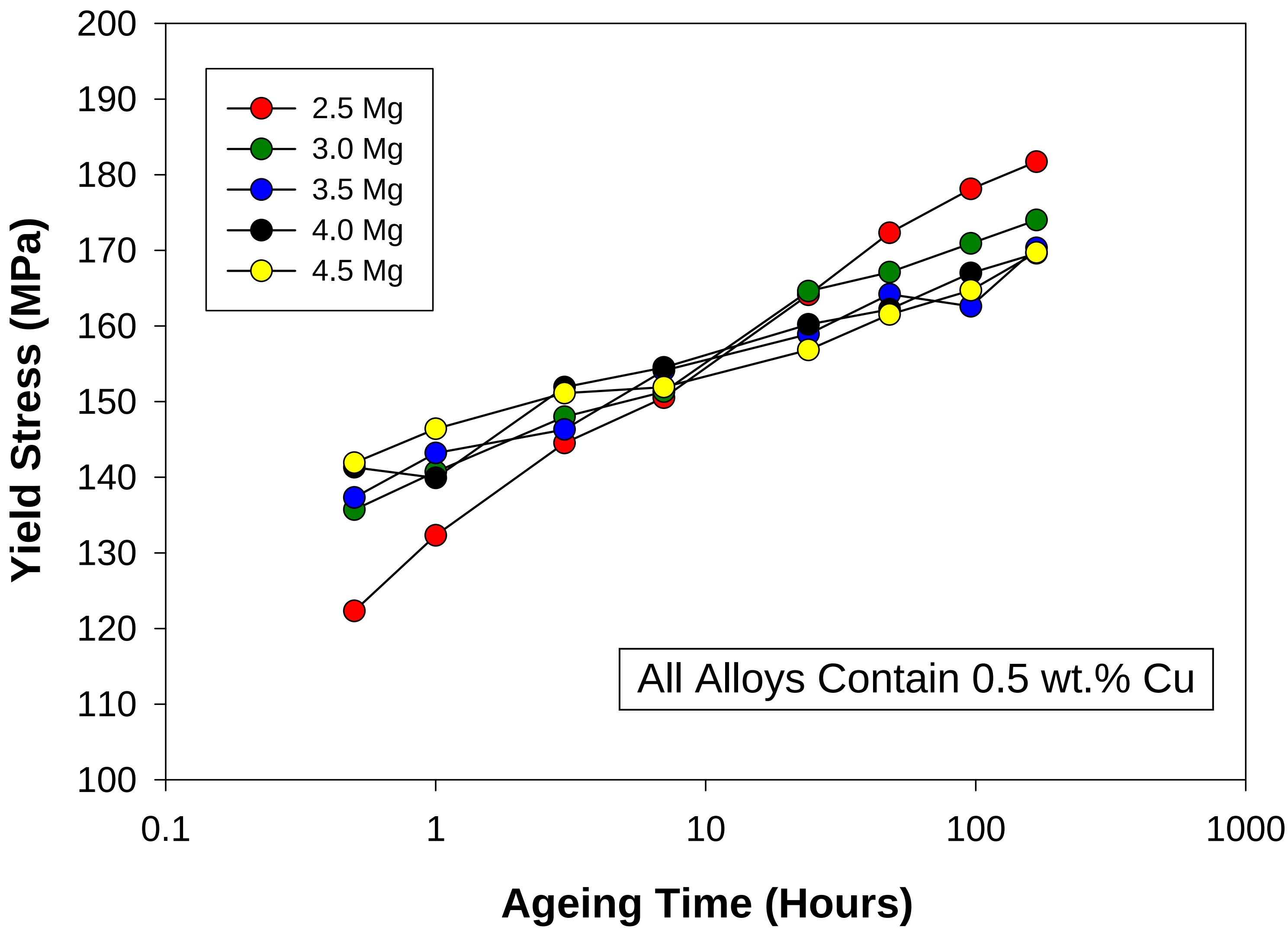
Alloy	Mg	Cu	Fe	Mn	Si
Al-2.5Mg-0.5Cu	2.4	0.48	0.11	0.25	0.12
Al-3.0Mg-0.5Cu	3.0	0.50	0.11	0.25	0.12
Al-3.5Mg-0.5Cu	3.4	0.50	0.11	0.24	0.12
Al-4.0Mg-0.5Cu	4.1	0.52	0.11	0.24	0.12
Al-4.5Mg-0.5Cu	4.6	0.52	0.10	0.25	0.13
Al-5.0Mg-0.5Cu	5.1	0.50	0.10	0.24	0.12

- Alloys lab cast and hot and cold rolled to 1mm thick sheet
- Solution heat treated at 550°C + Forced Air Quench
- Ageing temperatures of 140-200˚C

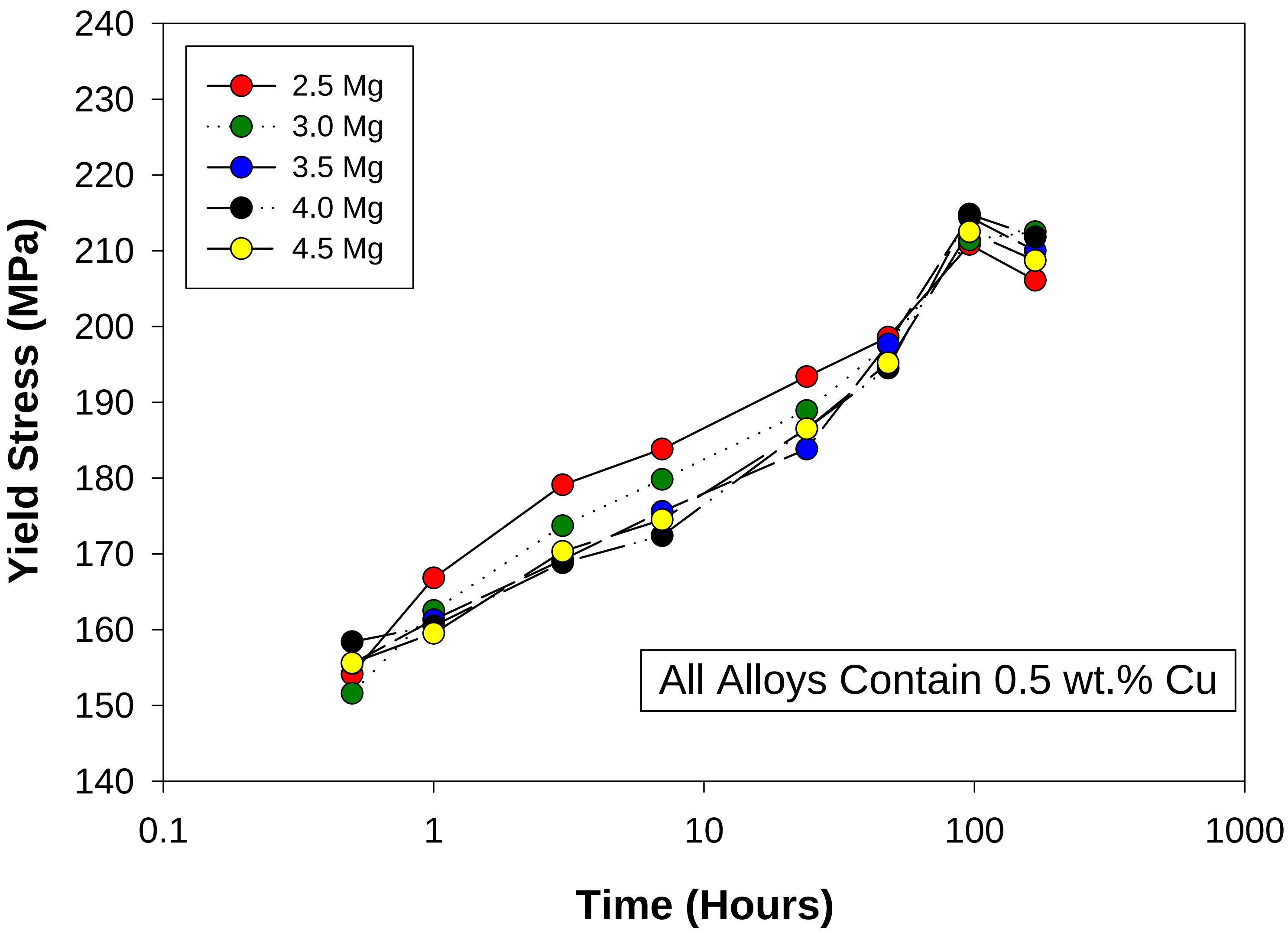
Rapid Ageing at 140ºC



Ageing at 140°C



Ageing at 200°C



Brief Summary of Properties

- Alloys of this type offer an excellent balance of relatively low as-received strength, good formability and a high paint bake strength (strength retention).

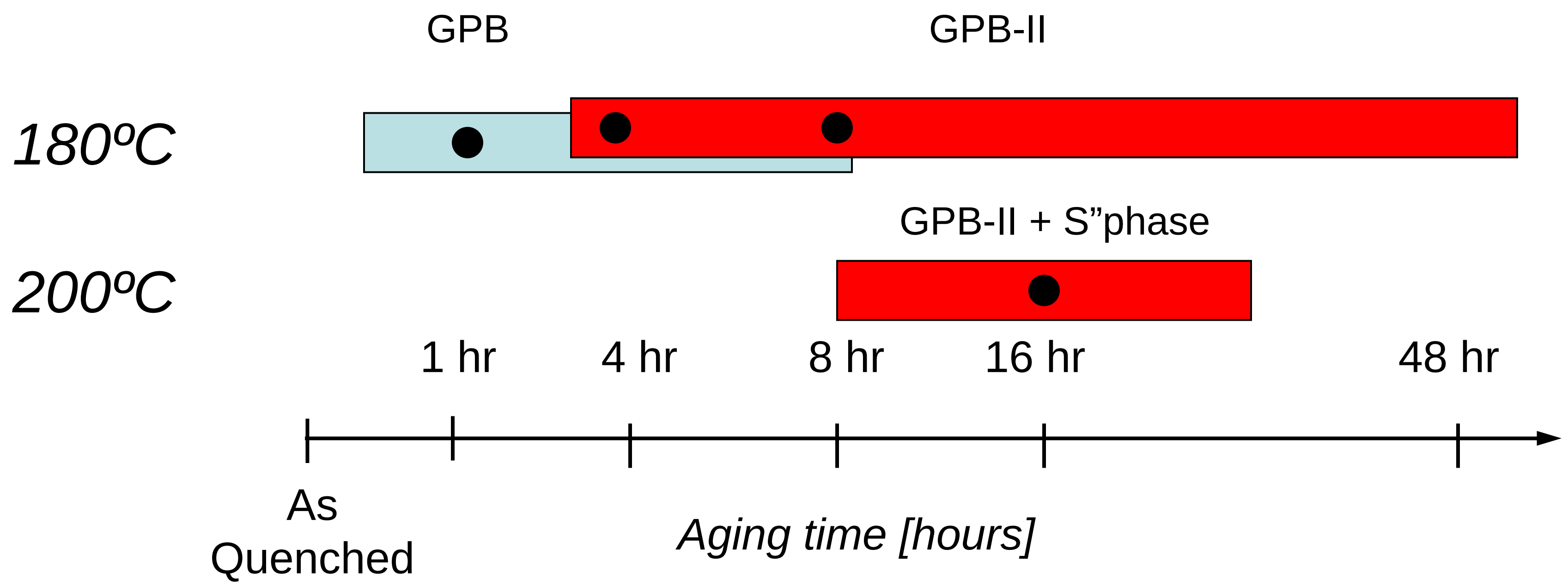
- Low Mg -containing alloys (eg, 1.5-2.5 wt.% Mg) show increased ageing kinetics as compared with higher Mg-containing alloys (3.0-4.5 wt.% Mg), for constant level of Cu.

- Alloys show no corrosion issues.
  - alloys containing up to 3.0 wt. Mg and up to 0.6 wt.% Cu not susceptible to inter-granular corrosion.

- However, the alloys show “stretcher strain” markings (Lüdering) and serrated flow.
  - limited to non-cosmetic applications, such as structures or inners.

Precipitation Processes in a Al-3.0Mg-0.4Cu (wt.%) Alloy *

* Al-3.3Cu-0.18 at.%



Potential Benefits & Potential Applications

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- Relatively high strength levels can be generated in stress corrosion resistant alloys (Al-Mg based, with Mg < 3 wt.%) through age hardening.
  - compare with AA5182 (4.5 wt.% Mg - stress corrosion and inter-granular corrosion sensitive).

- Alloys offer effective and rapid age hardening at relatively low temperatures (140-160°C).
  - important as the trend is to lower paint bake temperatures in automotive, from current 170-200°C to 150-160°C.
  - 6xxx alloys age very little at lower temperatures.

- Potential applications:
  - automotive structural and closure panel inner sheet.
  - non-auto applications - eg, beverage & food can stock, architectural sheet for façade.

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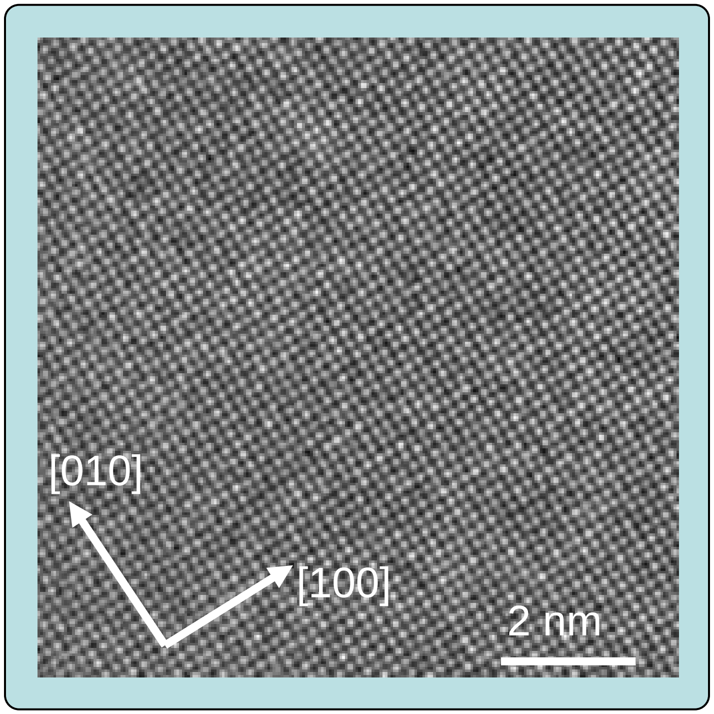
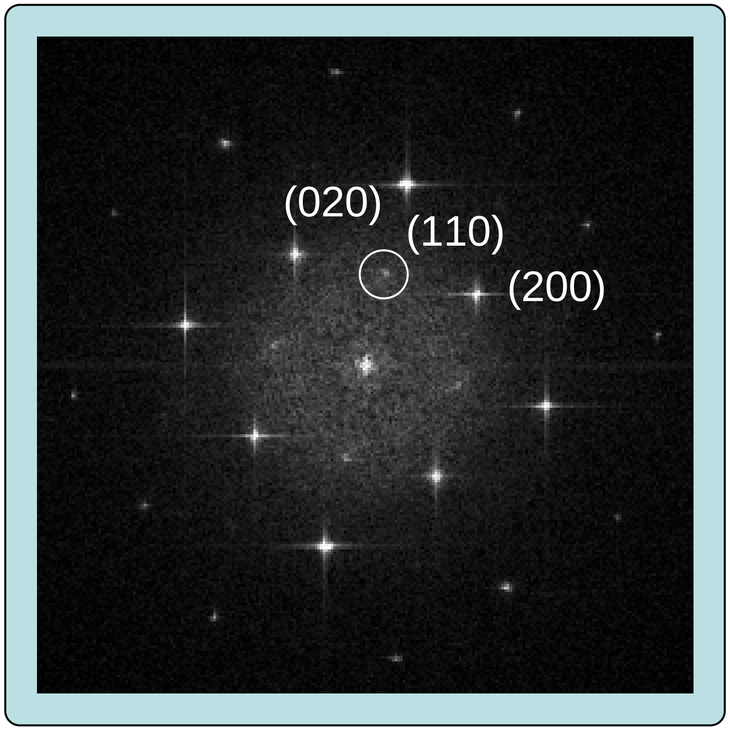
Shaping the future. Precisely.

Ageing of an Al-3.0Mg-0.4Cu (wt.%) Alloy - 1 hour at 180°C

No strain contrast detected



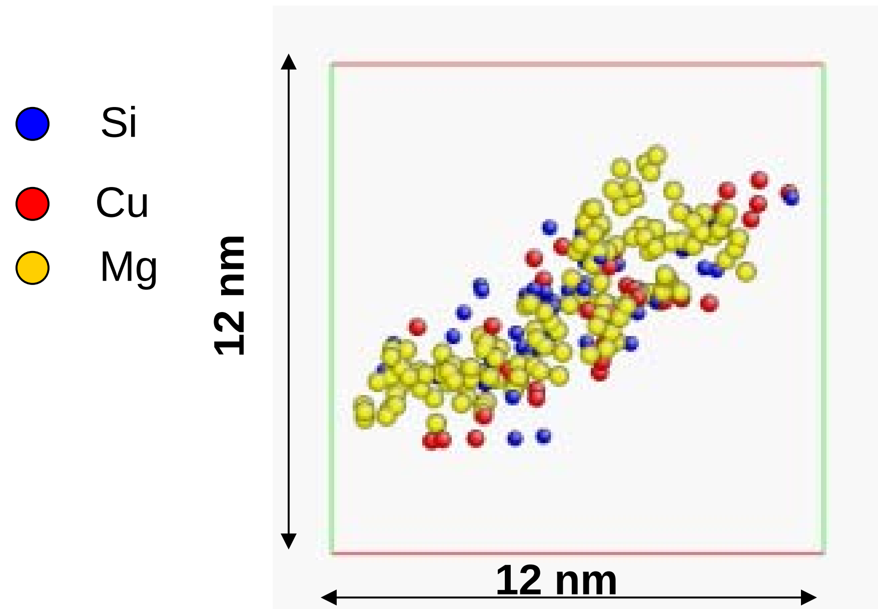
Presence of Superlattice reflections in the FFT Spectrum



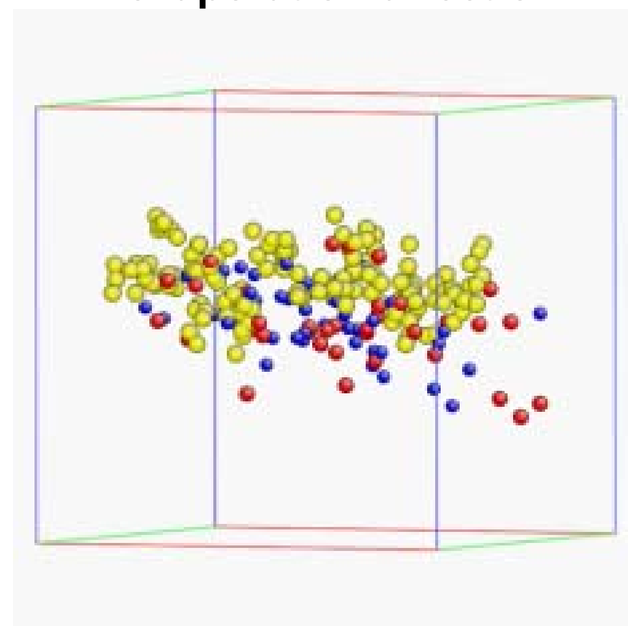
[001]Al zone axis

Ageing of an Al-3.0Mg-0.4Cu (wt.%) Alloy - 1 hour at 180°C

View along the evaporation direction



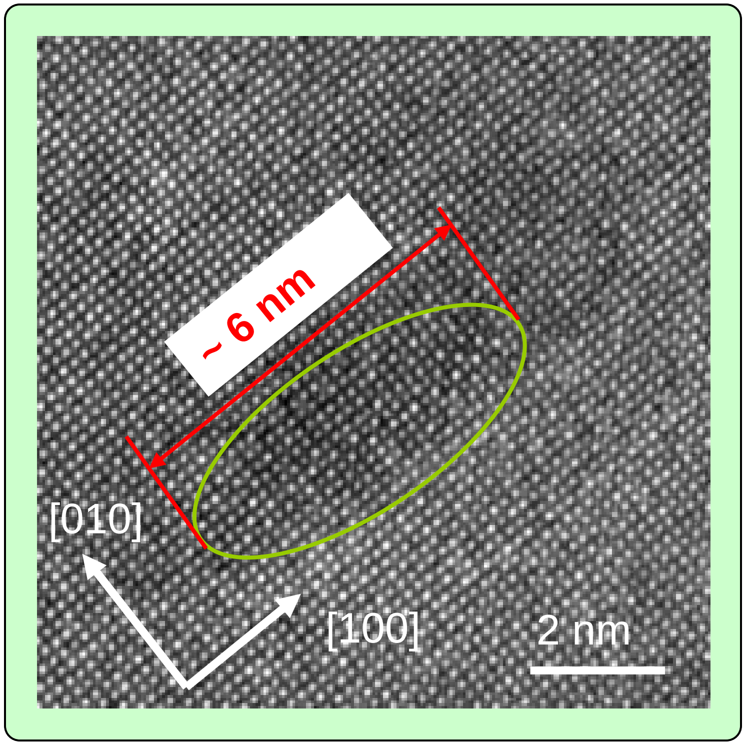
View perpendicular to the evaporation direction



	Mg/ (Si+Cu)	Mg/Si	Si/Cu
Average from 20 clusters	**1.72**	**2.92**	**1.40**

Ageing of an Al-3.0Mg-0.4Cu (wt.%) Alloy - 4 hours at 180°C

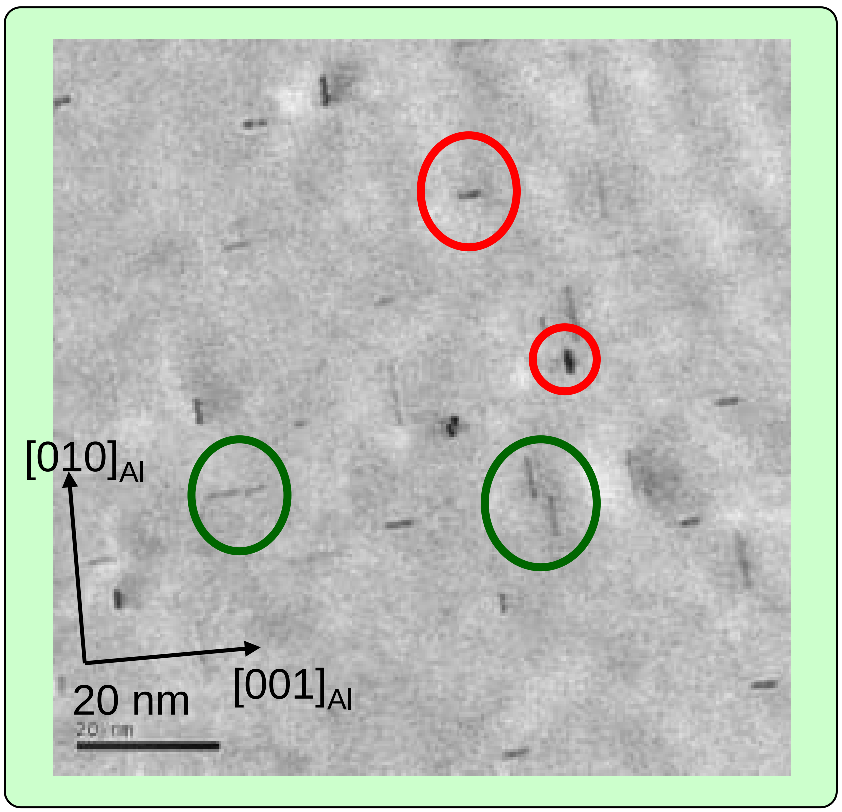
GPB zones directly visible in HRTEM Images and extended along [100]



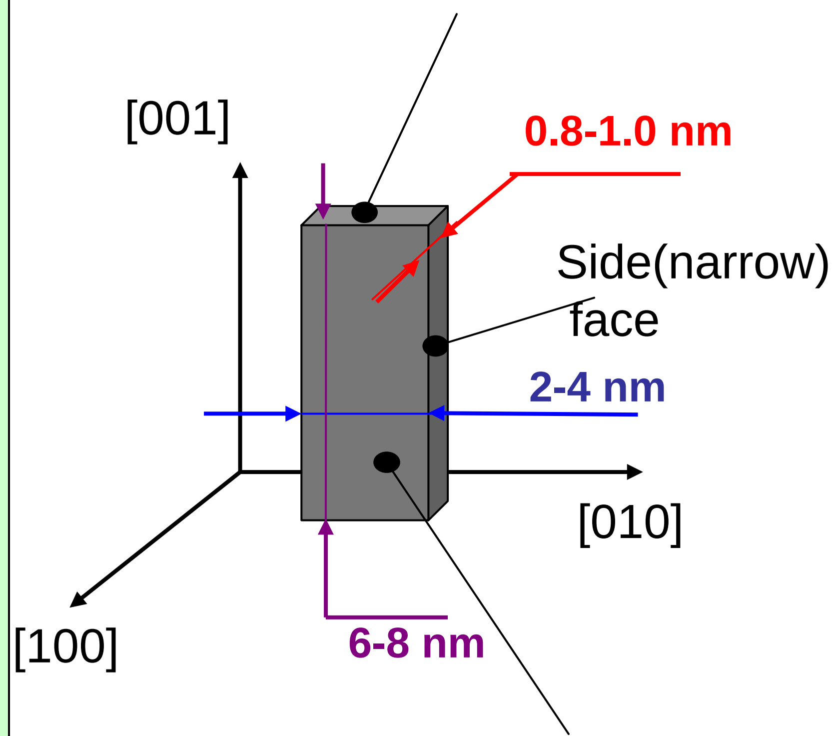
Ageing of an Al-3.0Mg-0.4Cu (wt.%) Alloy - 8 hours at 180°C

GPBII zones visible using conventional bright field TEM

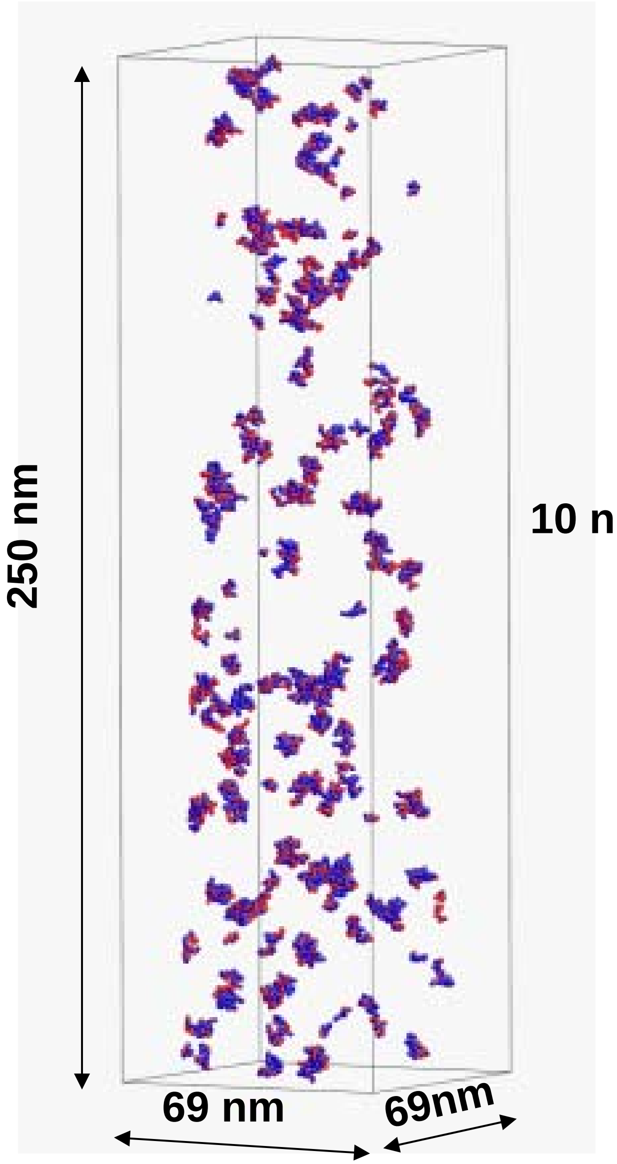
From <001>$_{Al}$

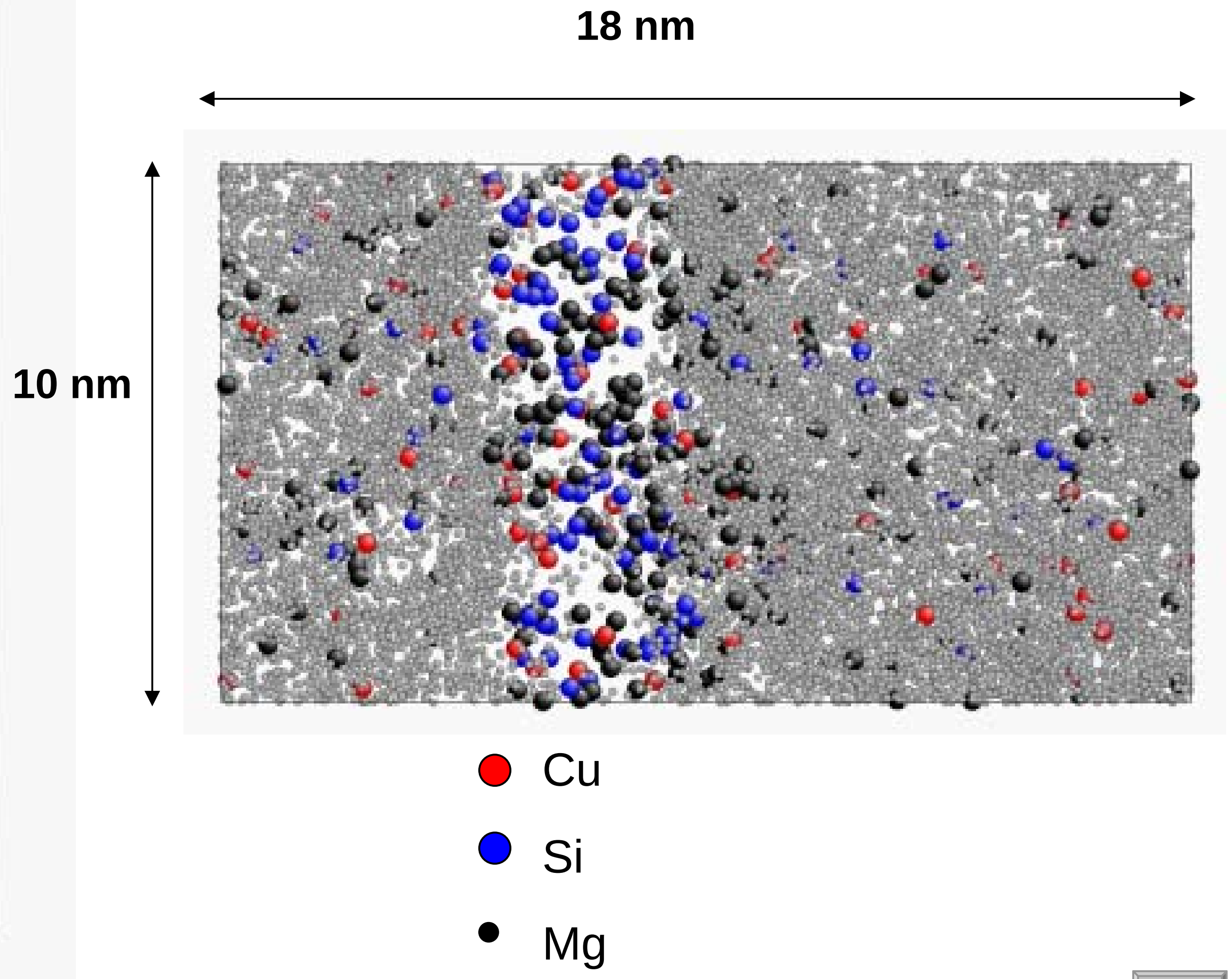


Variants of same particle

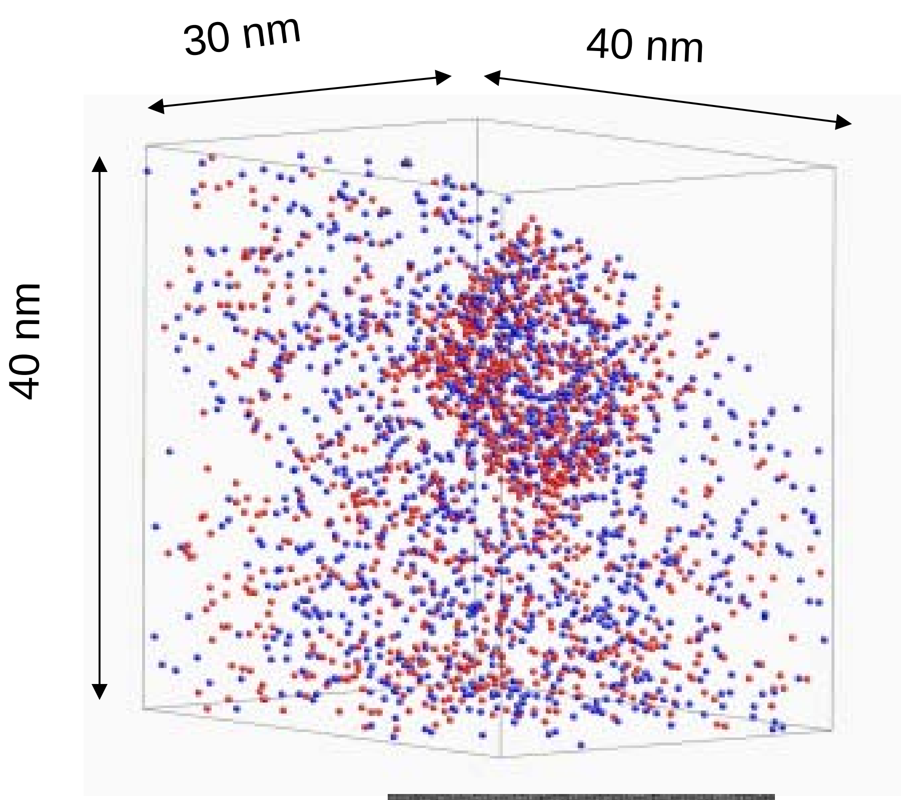


Ageing of an Al-3.0Mg-0.4Cu (wt.%) Alloy - 8 hours at 180°C

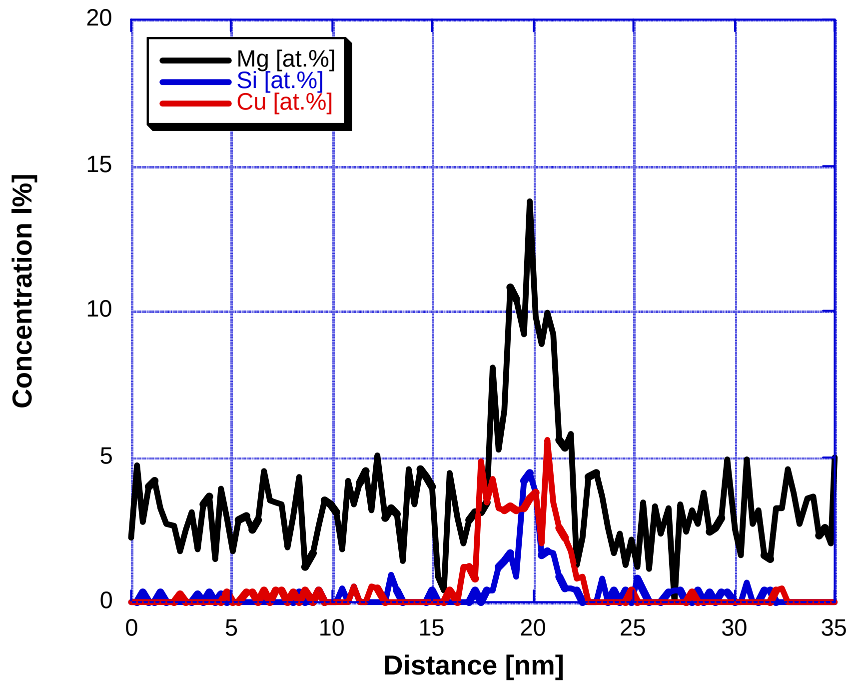


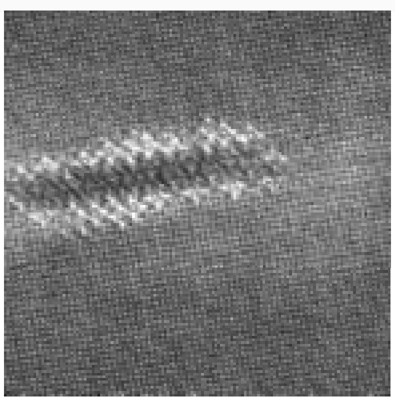


Ageing of an Al-3.0Mg-0.4Cu (wt.%) Alloy - 16 hours at 200°C



Compositional Profile Across the Plate-like GPBII zone





HAADF STEM image
(presence of a heavier element at the interface)

Precipitation Processes in a Al-3.0Mg-0.4Cu (wt.%) Alloy *

* Al-3.3Cu-0.18 at.%