Understanding Mechanical Properties of Castable alloy A205 by modelling and experiments

Projects
EXTREME
TRIPLE A

• Ceena Joseph
GKN Aerospace AB

Aluminium alloys offer…

- Low density (Potential weight reduction)
- Cheaper manufacturing costs

Aluminium vs Titanium

Alloys	Density (g cm^{-3})	Yield strength (MPa)	Operating temperature (^{o}C)
Al alloys	2.7	25 - 600	150 - 250
Ti alloys	4.5	170 - 1280	400 - 600

A205

"World's strongest Aluminium casting"

aeromet INTERNATIONAL LTD

- **Promising qualities**
  - High tensile strength
  - Good fatigue life
  - Good elevated temperature properties
  - Castablility

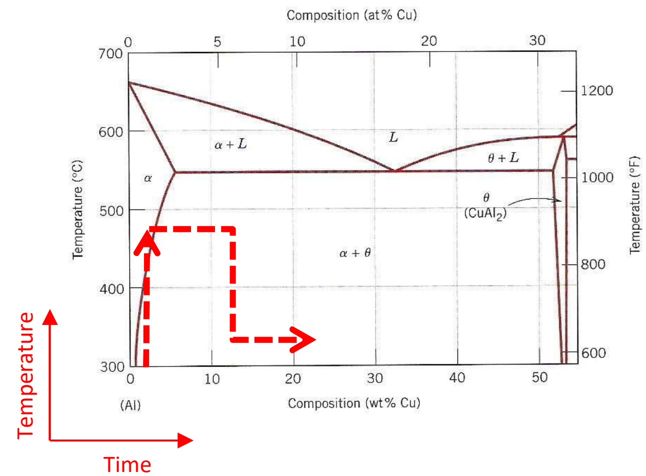
Chemical composition:

Elements	Al	Cu	(Ti)	(B)	Ag	Mg	Fe	Si	Other elements
Weight %	93.4	4.6	3.42	1.4	0.75	0.26	0.04	0.05	0.085

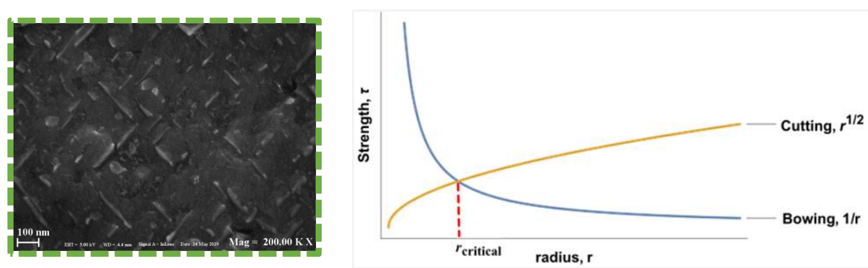
Phases present in A205

- Aluminium(α)
    - Matrix phase
- $CuAl_2$
    - Precipitation strengthening by Heat treatment
- Al_3Ti
    - Grain nucleant
- TiB_2
    - Grain refiner

Elements	Al	Cu	(Ti)	(B)	Ag	Mg
Weight %	93.4	4.6	3.42	1.4	0.75	0.26

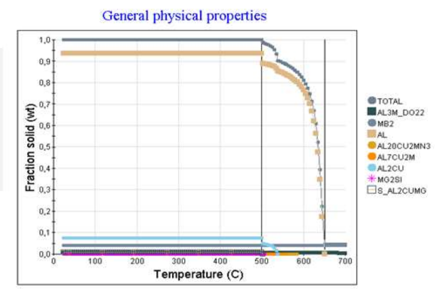


Al-Cu Phase diagram



Dislocation-Particle interaction

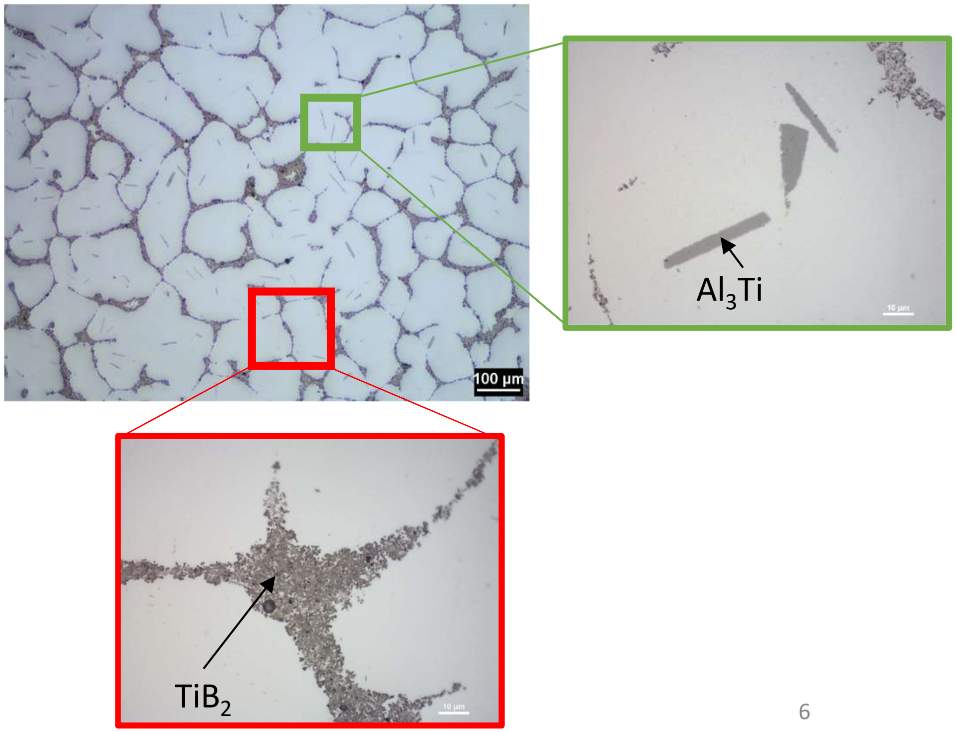
Phases present in A205



- Aluminium(α)
  - Matrix phase
- $CuAl_2$
  - Precipitation strengthening by Heat treatment
- Al_3Ti
  - Grain nucleant
- TiB_2
  - Grain refiner

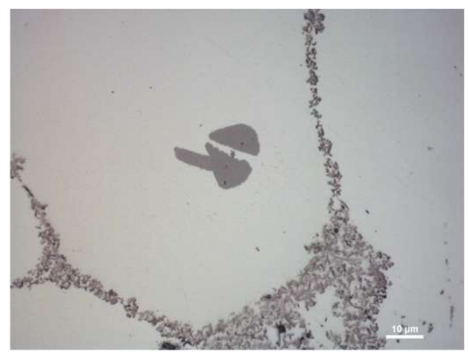
Elements	Al	Cu	(Ti)	(B)	Ag	Mg
Weight %	93.4	4.6	3.42	1.4	0.75	0.26

Microstructure of A205



Results: Al_3Ti particles in the Microstructure

- Al3Ti appear in different morphologies



Objectives

1. Heat treatment

Effect of aging temperature and time on hardness and microstructure

2. Thermal exposure

Effect on tensile properties with fractography

3. LCF life

Properties at elevated temperatures and effect of aging time with fractography

4. Property prediction

Applicability of ThermoCalc–Prisma;

Aging time optimization tool; LM-Parameter for strength prediction after thermal exposure

Objective

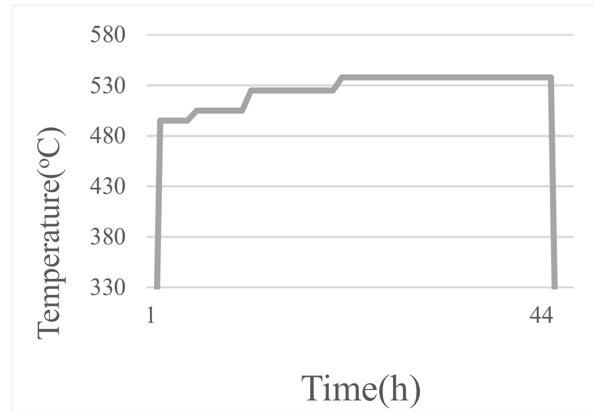
1. Heat treatment

- Effect of aging temperature and time on hardness and microstructure

Method

- **Solutionizing**
  - Hardness evolution
  - Microstructure
- **Relaxation**
- **Aging**
  - Hardness evolution
  - Microstructure

Solutionizing conditions

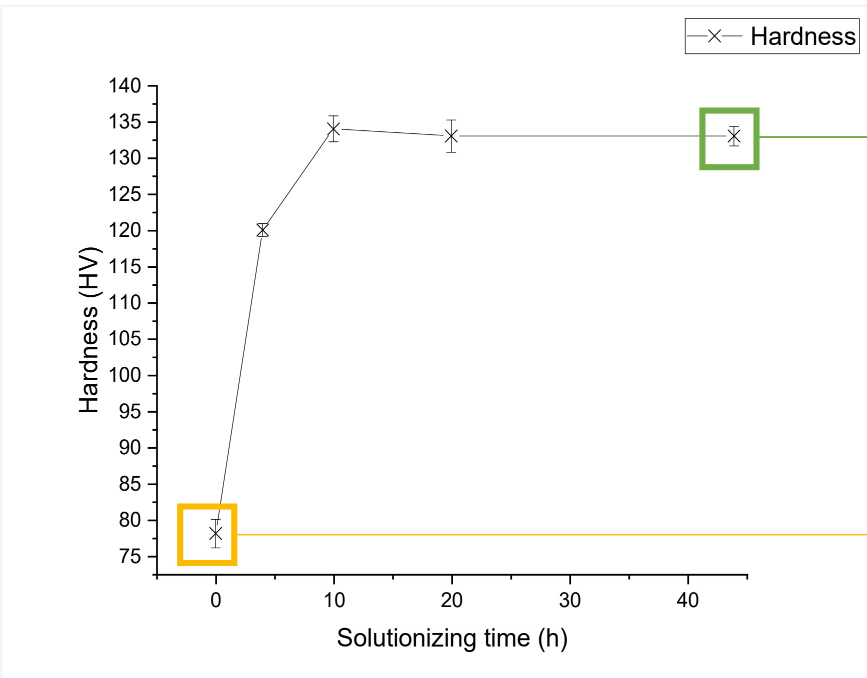


Aging conditions

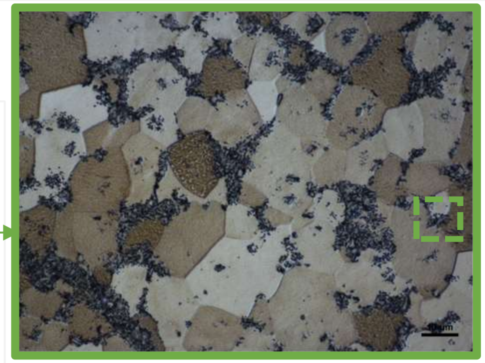
With relaxation		Without relaxation	
Aging temperature	Aging time	Aging temperature	Aging time
170°C	-	170°C	6 h
	10 h		10 h
	12 h		-
	16 h		16 h
205°C	0.5 h	205°C	0.5 h
	1 h		1 h
	2 h		2 h
	4 h		4 h

Results: Solution Treatment

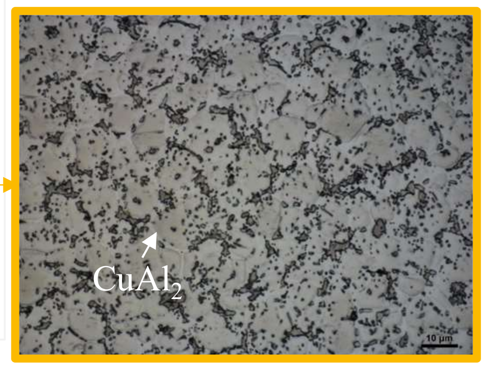
Hardness



- Solid solution strengthening over solutionizing



After solutionizing



Before solutionizing

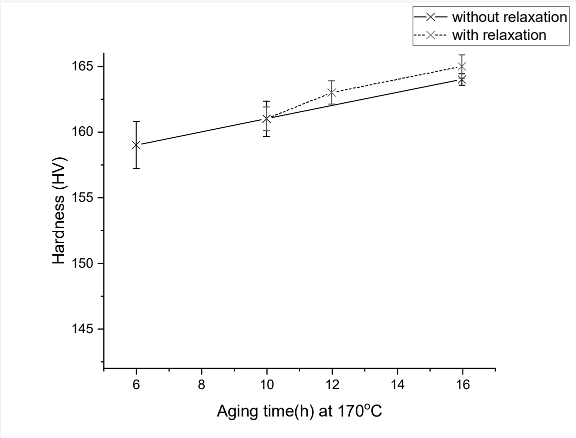
Microstructure

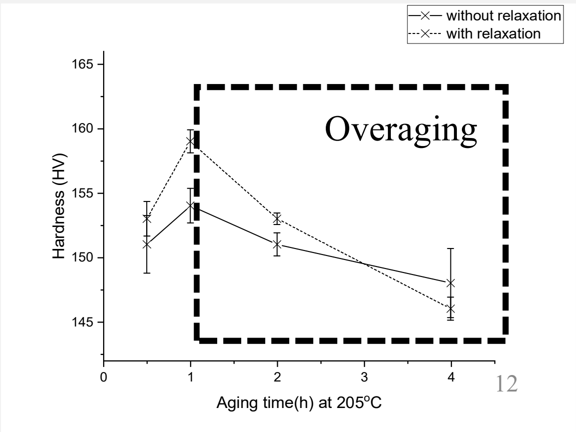
Results: Effect of Aging parameters

Hardness

- Aging temperature ⬆ → Time to reach peak hardness ⬇ >15 h
  → Peak hardness ⬇ >5 HV

- Relaxation slightly increases the peak hardness reached(1-5 HV)
- 16 hours at 170°C
- No noticeable effect on microstructure





Objective

2. Thermal exposure

- Effect on tensile properties with fractography

Method

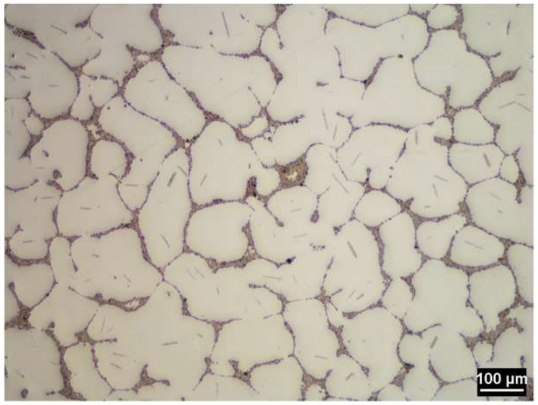
- Tensile properties analysed
  - Ultimate tensile strength(UTS)
  - Yield strength(YS)
  - Elongation to failure(%)
- Thermal exposure
- Testing temperature
  - 100°C to 250°C

Thermal exposure conditions

		Time	
Temperature	150°C	100 h	1000 h
	200°C	100 h	1000 h

> Starting material

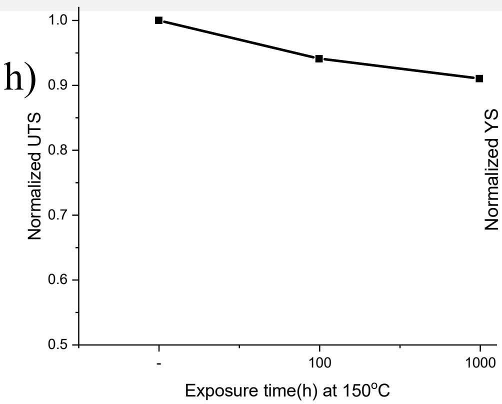
- T7 heat-treated
- *Grain size number*: 3
- *Hardness*: 160 HV

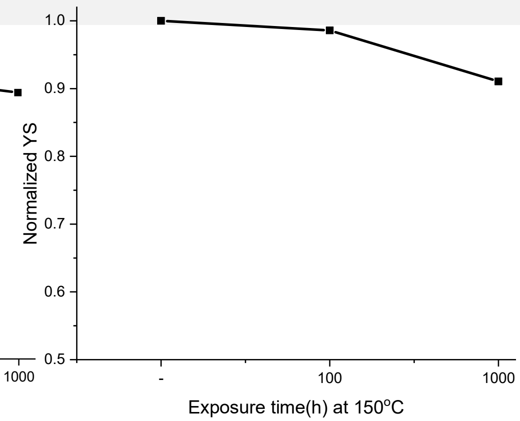


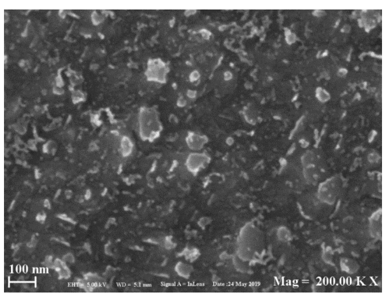
Microstructure of starting material

Results: Thermal exposure at 150^{o}C

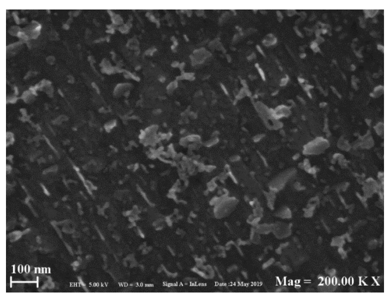
- Slow reduction in yield strength(-50 MPa/1000 h) and ultimate tensile strength(-40 MPa/1000 h)
- No significant change in elongation



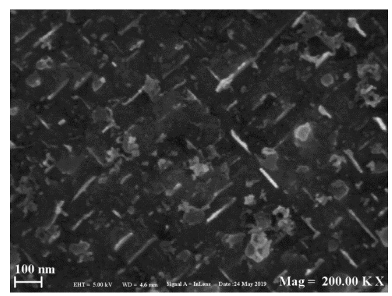




After T7 treatment

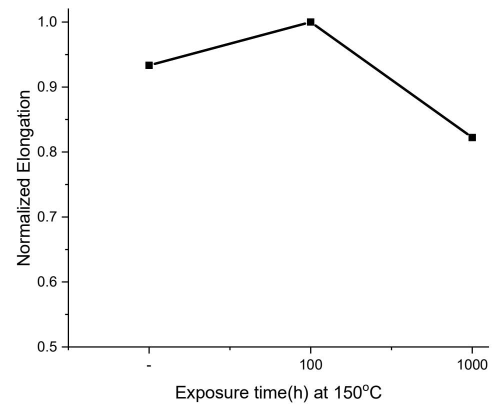


150^{o}C; 100 h



150^{o}C; 1000 h

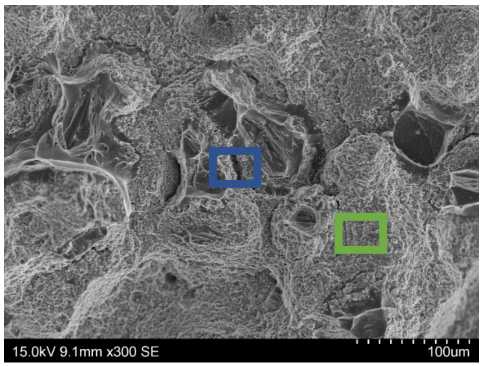
Coarsening of $CuAl_2$ precipitates

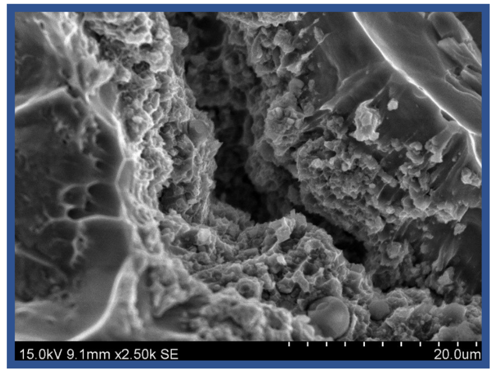


Tensile Properties

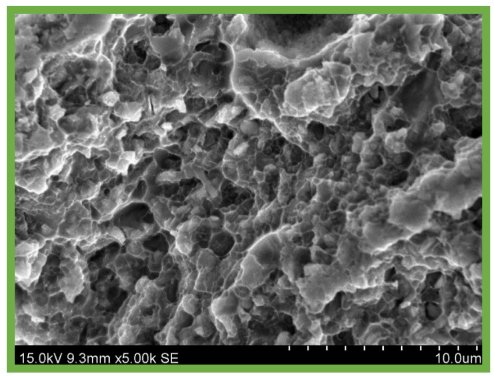
Results: Fractography

Thermal exposure at 150°C





Intergranular crack propagation

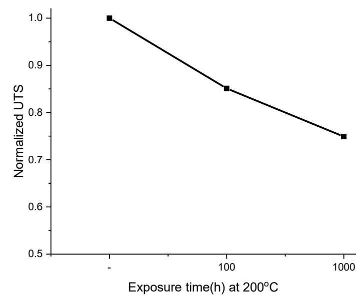


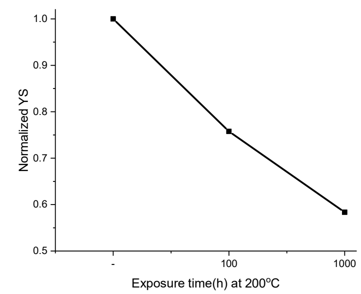
Microvoid coalescence

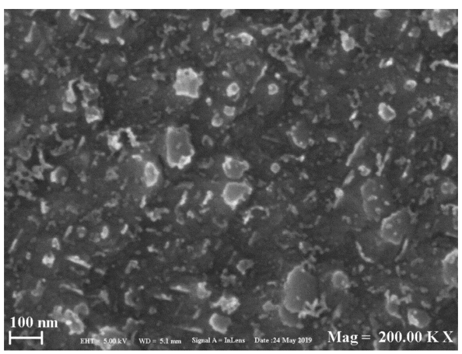
Crack propagation before and after prolonged exposure at 150°C

Results: Thermal exposure at 200°C

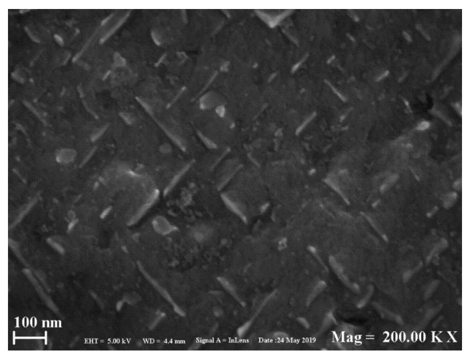
- Reduction in yield strength(-123 MPa) and ultimate tensile strength(-177 MPa) over time
- Significant increase in elongation
- Aggressive coarsening of $CuAl_2$ precipitates





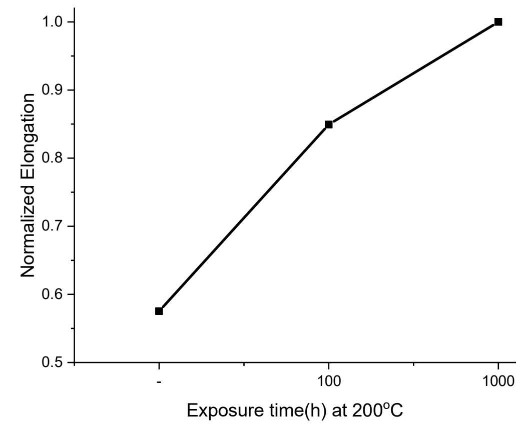


After T7 treatment



200°C; 100 h

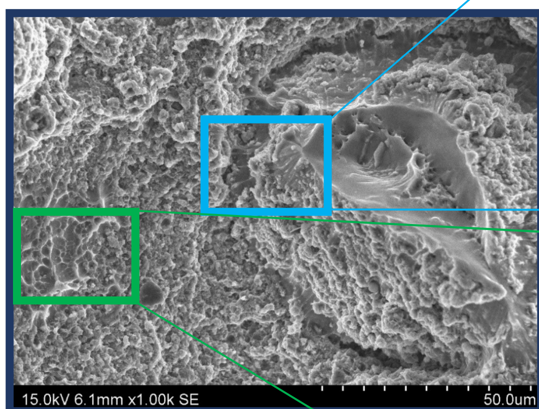
Coarsening of $CuAl_2$ precipitates

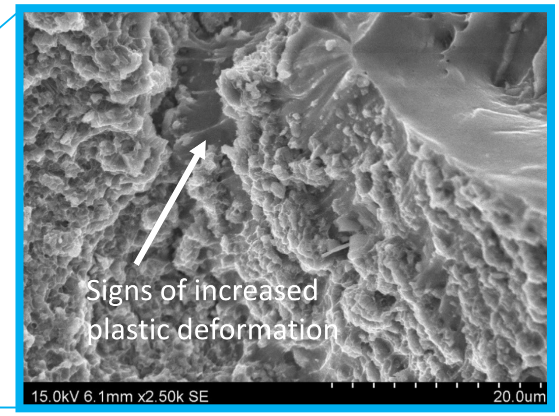


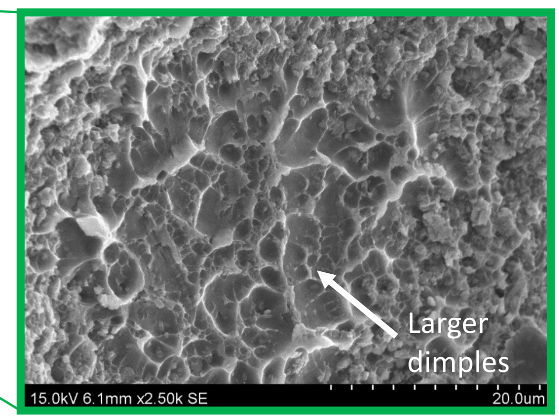
Tensile Properties

Results: Fractography

- **Prolonged exposure at 200^{o}C**



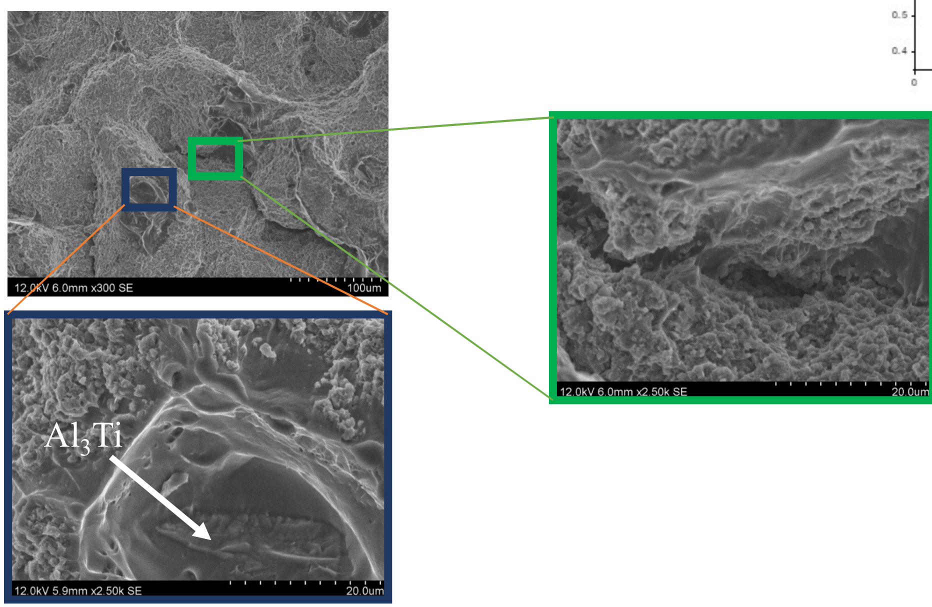




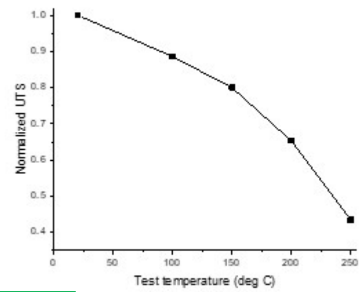
- Intergranular crack propagation with increased signs of deformation
- Mixed with MVC zones

Results: Effect on Tensile properties with Temperature

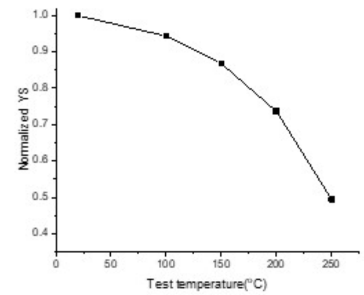
- Reduction in yield strength and ultimate tensile strength
- Elongation increases and then decreases with increasing test temperatures



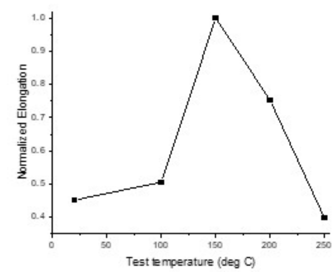
Intergranular crack propagation



(a)



(b)



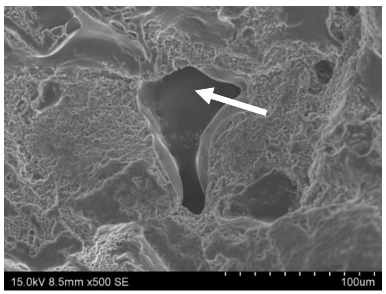
(c)

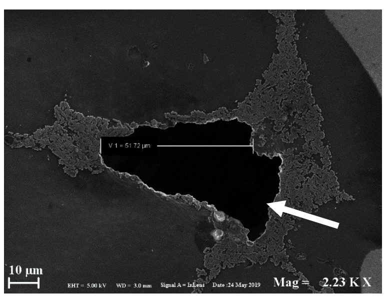
Tensile Properties

Results: Causes for scatter in properties

Casting defects

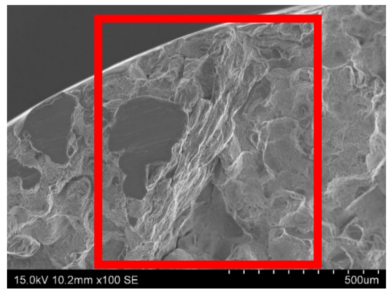
Porosities



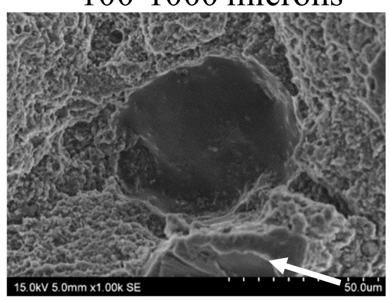


100-300 microns

Oxide inclusions



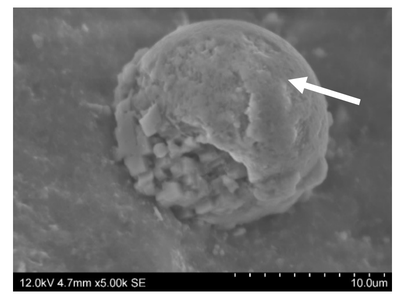
100-1000 microns



20-200 microns

EDX	Element	O	Cu	Al	Ti
		5.95	3.07	47.49	43.49
	Wt%	2.51	10.2	76.9	10.32

Cryolite inclusions



5-10 microns

Element	F	Mg	Al	K	Ti
Wt%	20.01	15.56	12.95	47.51	3.97

Objective

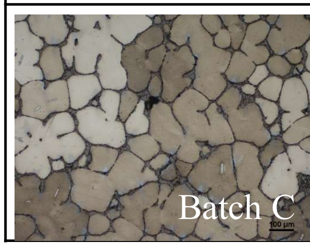
3. LCF	• Properties at elevated temperatures and effect of aging time with fractography

Method

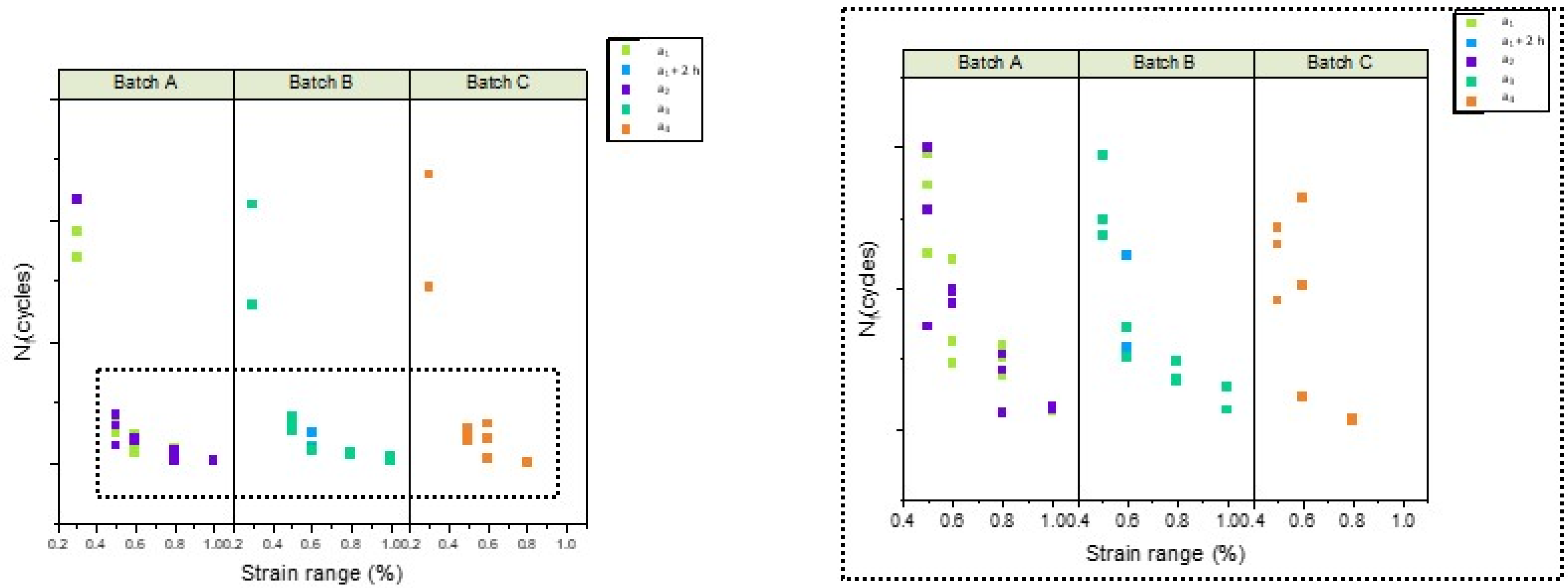
- Starting material
  - 3 different batches(A, B and C)

- All batches were tested at different strain ranges

Used for elevated temperature testing

Microstructure	Grain size number	Condition
	6.5	Solutionized; Aged to 6 h and 10 h
	4	Solutionized; Aged to 8 h and 12 h
	2.5	Solutionized; Aged to 16 h(complete T7 treatment)

LCF Properties



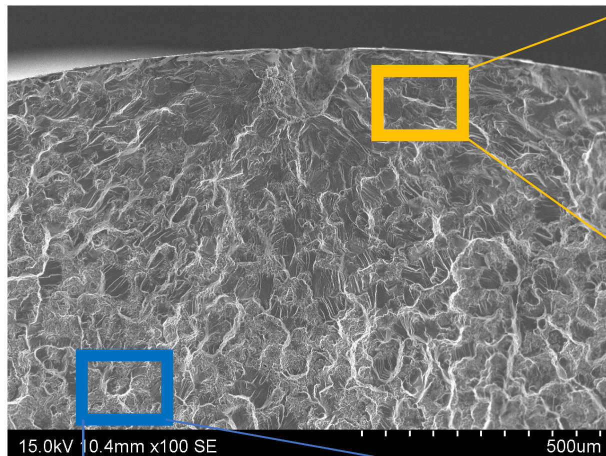
(b)

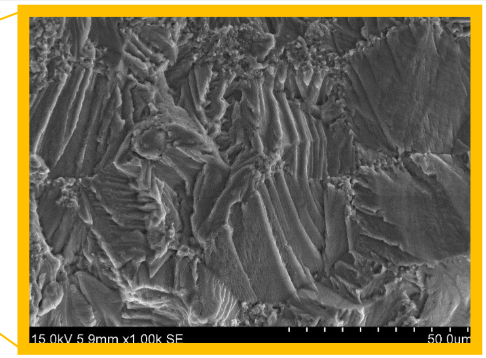
LCF life(N_f) of Batches – A, B and C of A205 tested at different strain ranges after different aging times(coloured as shown in legend). The clustered data points in (a) corresponding to test strain ranges above 0.3% are expanded in (b) [Y-axis has been removed for confidentiality purposes]

Results: Fractography

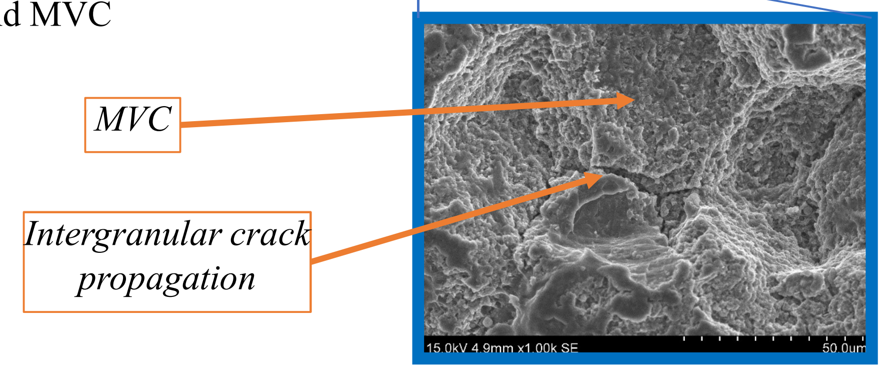
Irrespective of testing and aging conditions

- Clear initiations
- Faceted crack growth
  - Region II crack propagation zone
  - Transgranular
- Overstress region
  - Mostly intergranular and MVC





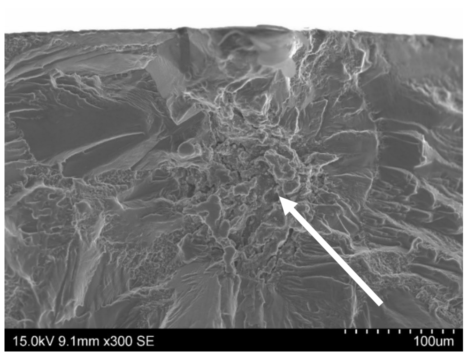
Faceted crack growth

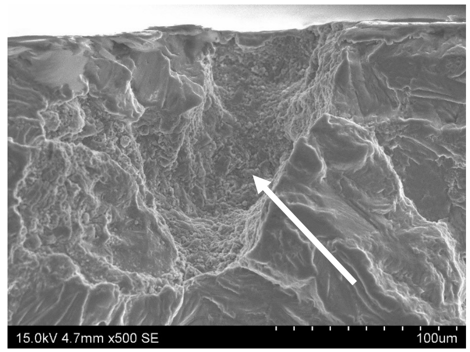


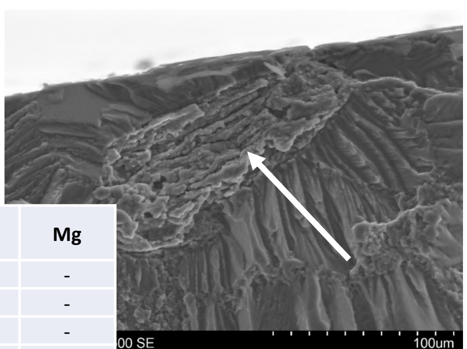
Results: Crack initiators

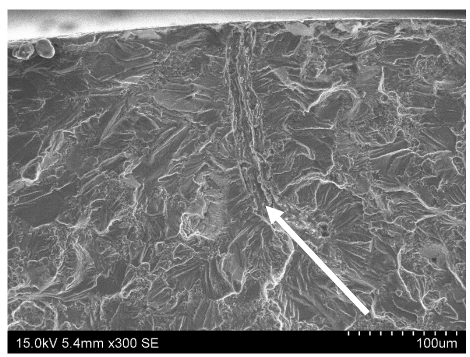
Oxide inclusions: 100 microns to 1 mm

EDS analysis

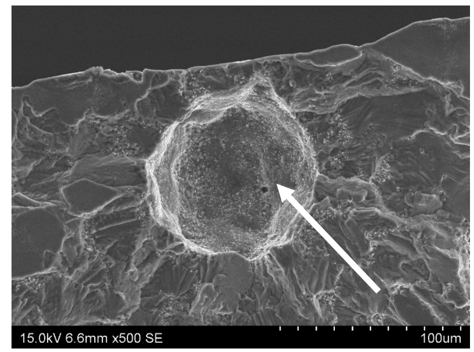








Porosity: 100 to 300 microns



Element	O	Cu	Al	Ti	Mg
Wt%	5.95	3.07	47.49	43.49	-
	1.77	6.49	70.13	21.62	-
	2.33	4.44	70.51	22.72	-
	8.71	2.85	53.5	30.9	4.03

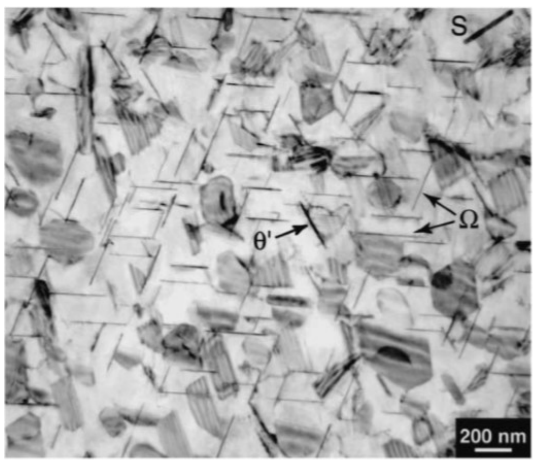
Objective

4. Property prediction	Strength after prolonged thermal exposures; Aging time optimization tool; LM-Parameter for strength prediction after thermal exposure

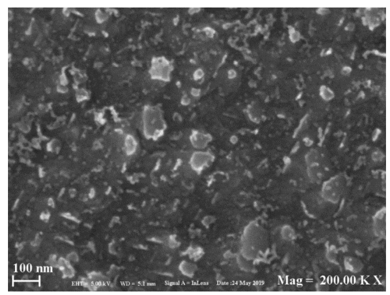
Calibrating PRISMA using Experimental values

- **Resolution of FEG SEM(10 nm) is insufficient for $CuAl_2$ analysis**

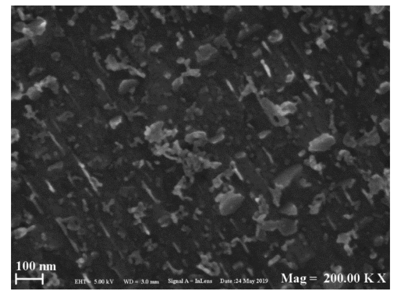
Expected resolution(TEM):



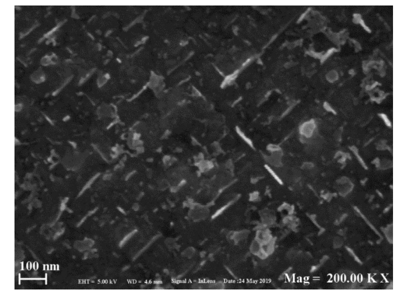
θ' and Ω precipitates in an Al–4Cu–0.3Mg–0.4Ag (wt. %) alloy after solutionizing and aging at 250°C for 10 h(1)



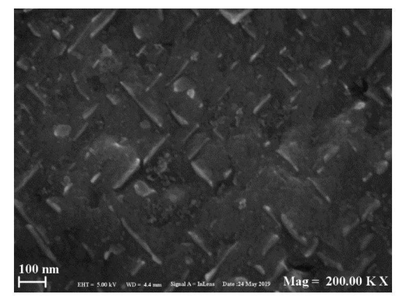
T7 treatment



150°C; 100 h



150°C; 1000 h



200°C; 1000 h

SEM analysis: Evolution of $CuAl_2$ precipitates during thermal exposures

Conclusions

- **Effect of aging times and temperature**
  - Increasing aging temperature brings down the time to reach peak hardness
- **Effect of thermal exposure**
  - Prolonged exposures at 150^{o}C and 200^{o}C adversely affects the strength
- **LCF life**
  - Life depends on the size of defects at or under the surface
  - Casting quality has to be improved to prevent defects

- **Demonstrator in A205**

- Thanks for your attention !

- **Team** @GKN

Anders Sjunnesson , Bengt Pettersson , Thomas Kruslind , Ceena Joseph

Masters student : Monish Rajkumar