Achievements and future challenges in Magnesium Alloy Research and Application in Australia

By Mark Easton
Mark Gibson, Suming Zhu, Trevor Abbott, Jian-Feng Nie, Gary Savage, Carlos Cáceres, and many others

RMIT UNIVERSITY

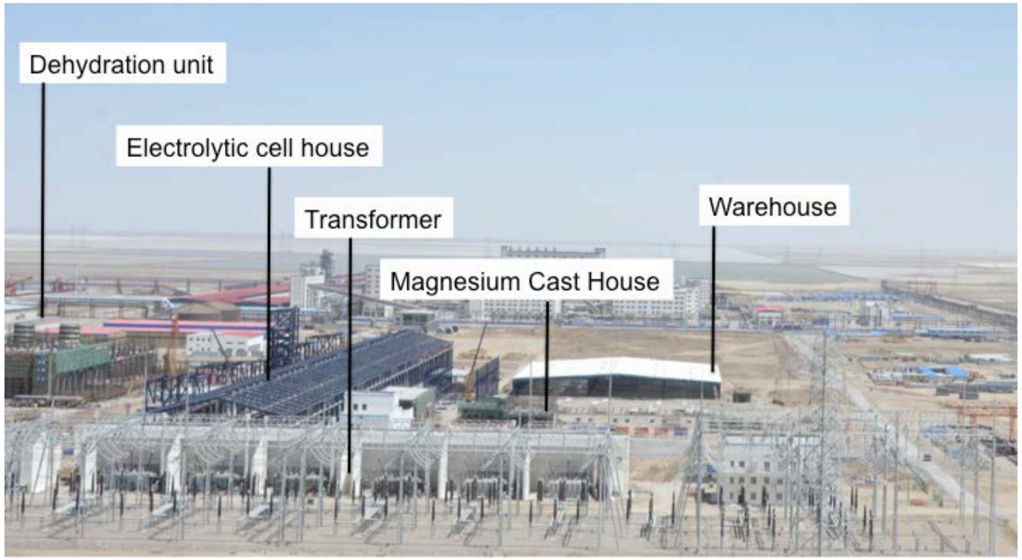
Magnesium Research in Australia

- Australian Light Metals Action Agenda in 2001
- Originally developing a primary Mg smelter project in Australia – but cancelled in 2004 due to low metal prices
- Research Organizations (all focused on light metals in general)
  - CAST Co-operative Research Centre 1993-2013
    - Industry engaged applied research
  - CSIRO Light Metals Flagship 2003-2011
    - Strategic research focused on step change industry opportunities
  - Centre of Excellence in the Design of Light Metals 2005-2013
    - Directed fundamental alloy design research
- Whilst these centers have been closed there is still a strong legacy of capability and projects in Australia

What is happening in the Mg world?

- Lots!!
- Light weighting is definitely the issue of the moment, particularly in Europe but also in North America (Ford F150 moving to an Al body structure)
- Substantial interest/new orders for advanced Mg alloys from automotive OEMs

- New smelter in Golmud, Qinghua province
- Electrolytic Mg (old Bécancour plant)
- Magontec to produce 45ktonne Mg alloys/year
- Mostly hydro-power 6.5tonnes CO_2/tonne Mg (compared with 25tonnes for Pigeon process in China)



Current Magnesium Research Projects

- LP130100828 High Performance Cast Magnesium Alloys
  - Understanding Mg-Al-RE alloys for higher strength-ductility combinations, for high temperature performance and improved castability (particularly YS)
  - CIs Easton (RMIT), StJohn, Nogita, Caceres (UQ), Chen (Monash), PIs Abbott (Magontec), Schmid-Fetzer (Claustal), Gibson (CSIRO)
- Commercial Research Project
  - Targeted alloy development in the Mg-Al-RE system for HPDC
  - Funded by two European OEMs
- Proposed Prototyping Project
  - Italian automotive component – using AM-SC1 to prototype an AE44 alloy in Victorian SMEs
- Baosteel Australia joint research and Development Centre projects predominantly at Monash University focusing on wrought alloys and coatings

So what has happened to the technologies?

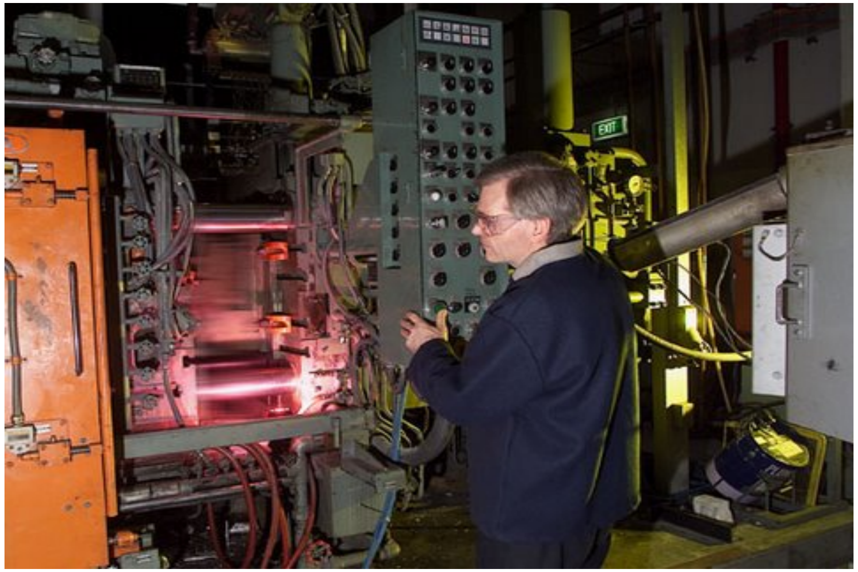
- AMCover (low GHG cover gas)
  - Used quite widely in the industry. Patents dropped and little revenue could be generated from it. Lots of GHG saved.
- Alloys
  - AM-lite (Mg-Zn-Al alloys, decorative alloys): Magontec had a ZA128 alloy compared with the ZA124 alloy from CAST. Best compromise around ZA126. Some small sales of alloys.
  - AM-CAST (now called MicroZir, a Mg-Zr grain refiner): Magontec are now producing it and finding a lot of interest in the market place.
  - AM-SC1 (sand-cast creep resistant alloy): About to be used as a prototype for AE44
  - AM-HP2/HP3/HP2plus (HPDC creep resistant alloys): Commercialization on hold. Performance of alloys are beyond what is currently needed. Higher cost due to use of expensive REs (Nd, Y).
  - AM-EX1 (extrusion alloy): Current development project with LKR. Commercial prospects unclear.
  - Mg-Al-RE alloys (creep resistant/structural alloy): New provisional patent and focus on ongoing research
- Laser Assisted Self Piercing Riveting
  - Licensed to Henrob, a successful demonstration cell developed as part of the US-AMP program
- Casting technologies (CSIRO)
  - Twin roll casting: still lots of interest in the market place but volumes are low
  - T-Mag (gravity tilt casting): spin off company

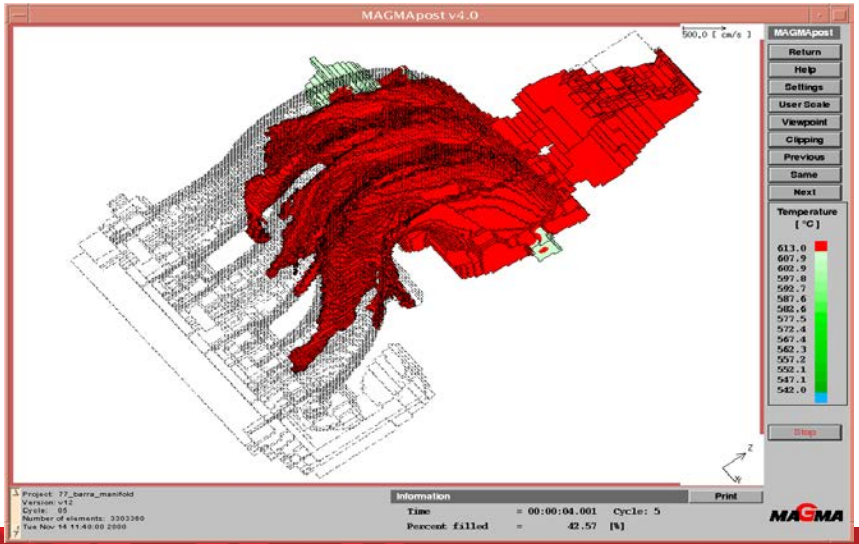
Capabilities: Alloy Production

- CSIRO and smaller scale at University of Queensland
- Two light alloy furnaces 30kg Mg
- Heat treatment
- Mg machining area
- Melt centrifuge
- Cover gas
- Spectrometer – calibrated for REs
- J.Mat.Pro and Pandat Mg alloy database

High Pressure Die Casting

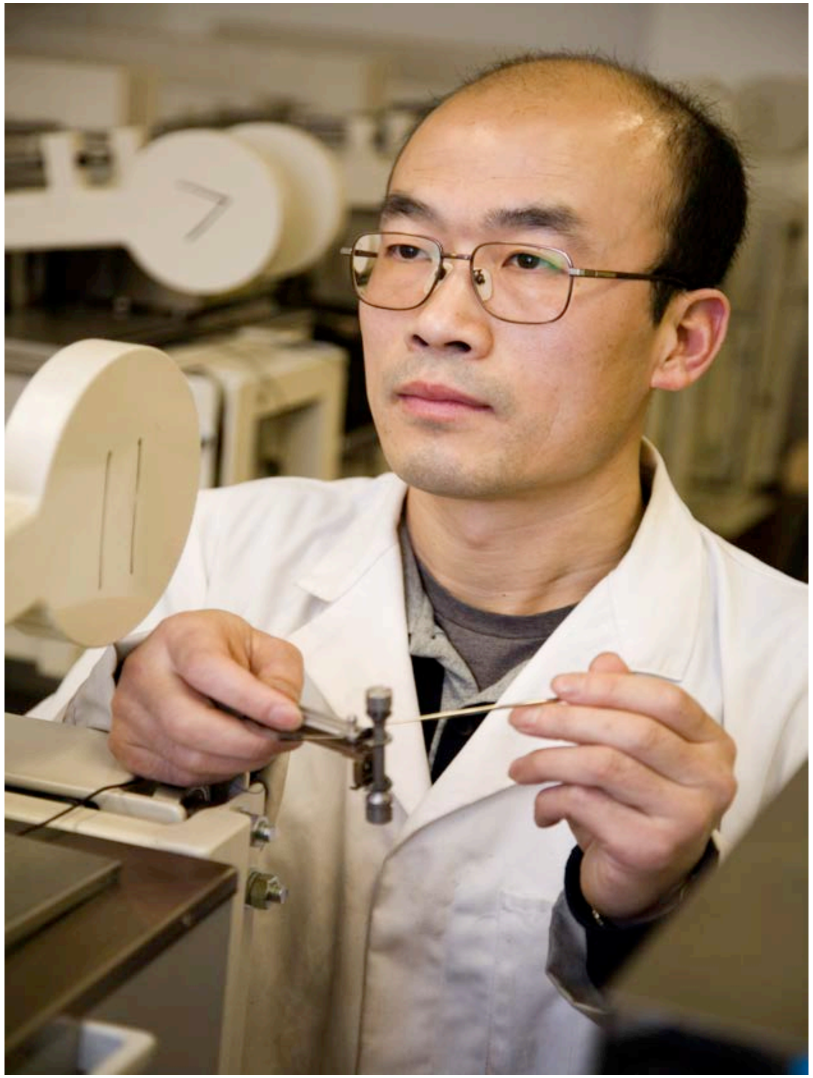
- CSIRO Clayton
- Toshiba 250T cold chamber high pressure die casting machine
- Rauch Magnesium Mobile Melter and Dosing Furnace
- Casting Simulation Software: MAGMAsoft, FLOW-3D, Calcosoft



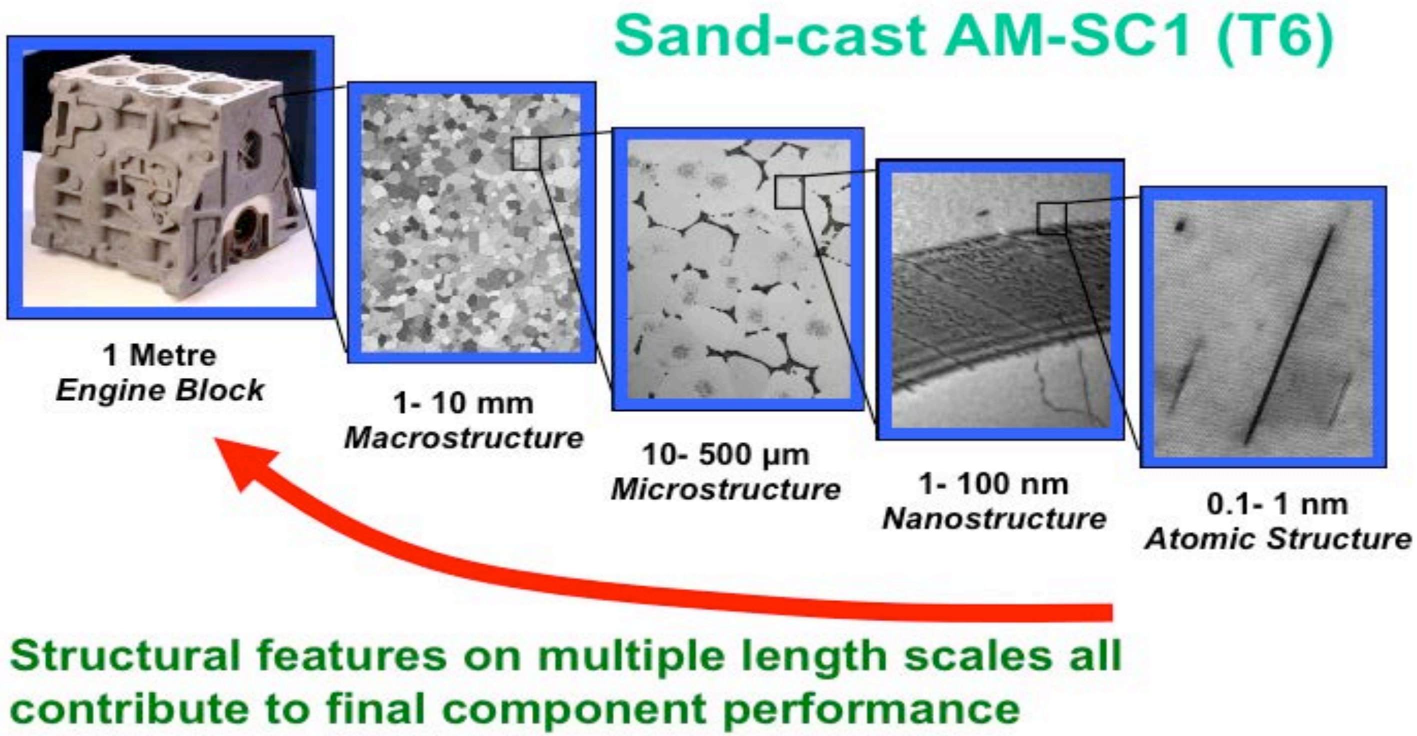


Property Testing

- Hardness
- Tensile
- Creep (24 arms across CSIRO and Monash)
- Bolt Load Retention (UQ)
- Fatigue – stress and strain controlled (CQU)
- Some physical properties
- Corrosion – Polarisation, Immersion, Salt spray, Outdoor exposure (Monash, UQ, CQU)



Microstructural Characterisation

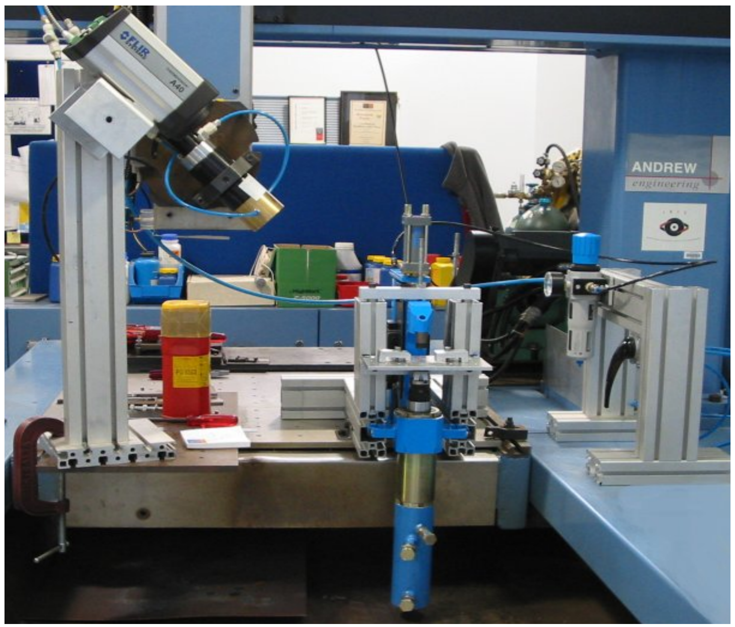


Facilities across Monash, UQ, CSIRO, Deakin, RMIT

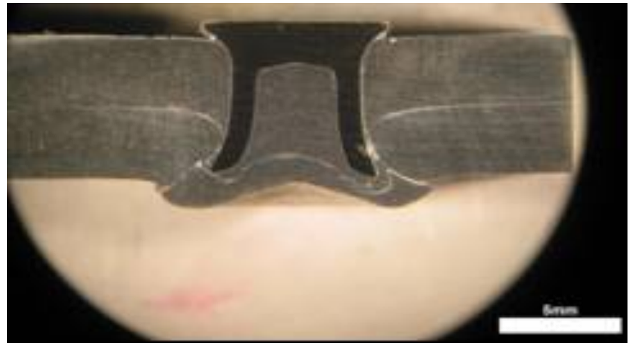
- SEM – EDS, WDS, EBSD, FIB
- TEM – including HR-TEM, Titan (Monash)
- Atom Probe (x2 Monash)

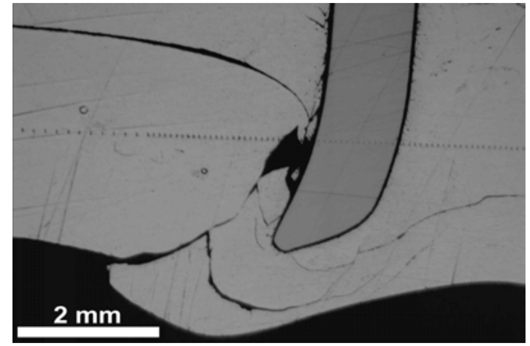
Joining

Laser Assisted
Self Piercing Riveting
-licensed to Henrob

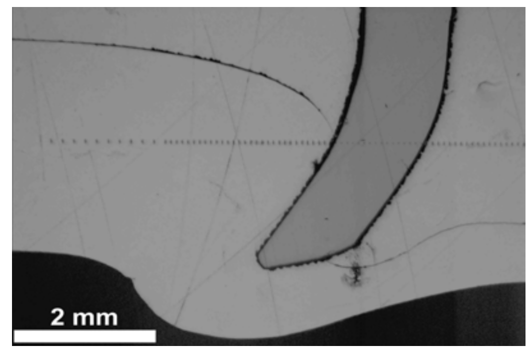


Without Laser





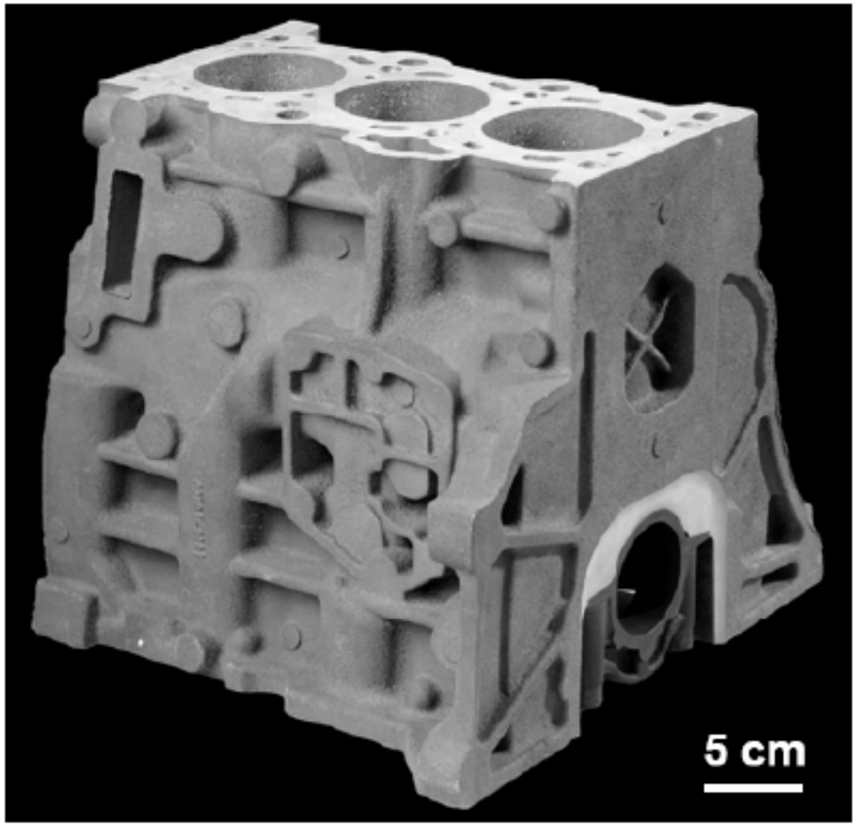
With Laser



Magnesium Alloys and CAST

- CAST Co-operative Research Centre existed for over 20 years
- A large effort into Magnesium Alloys
- This presentation attempts to bring together some of the major learnings about magnesium alloys

- Since CAST ended I have moved to RMIT University



AVL AM-SC1 crankcase

Mg alloys – what have we learnt?

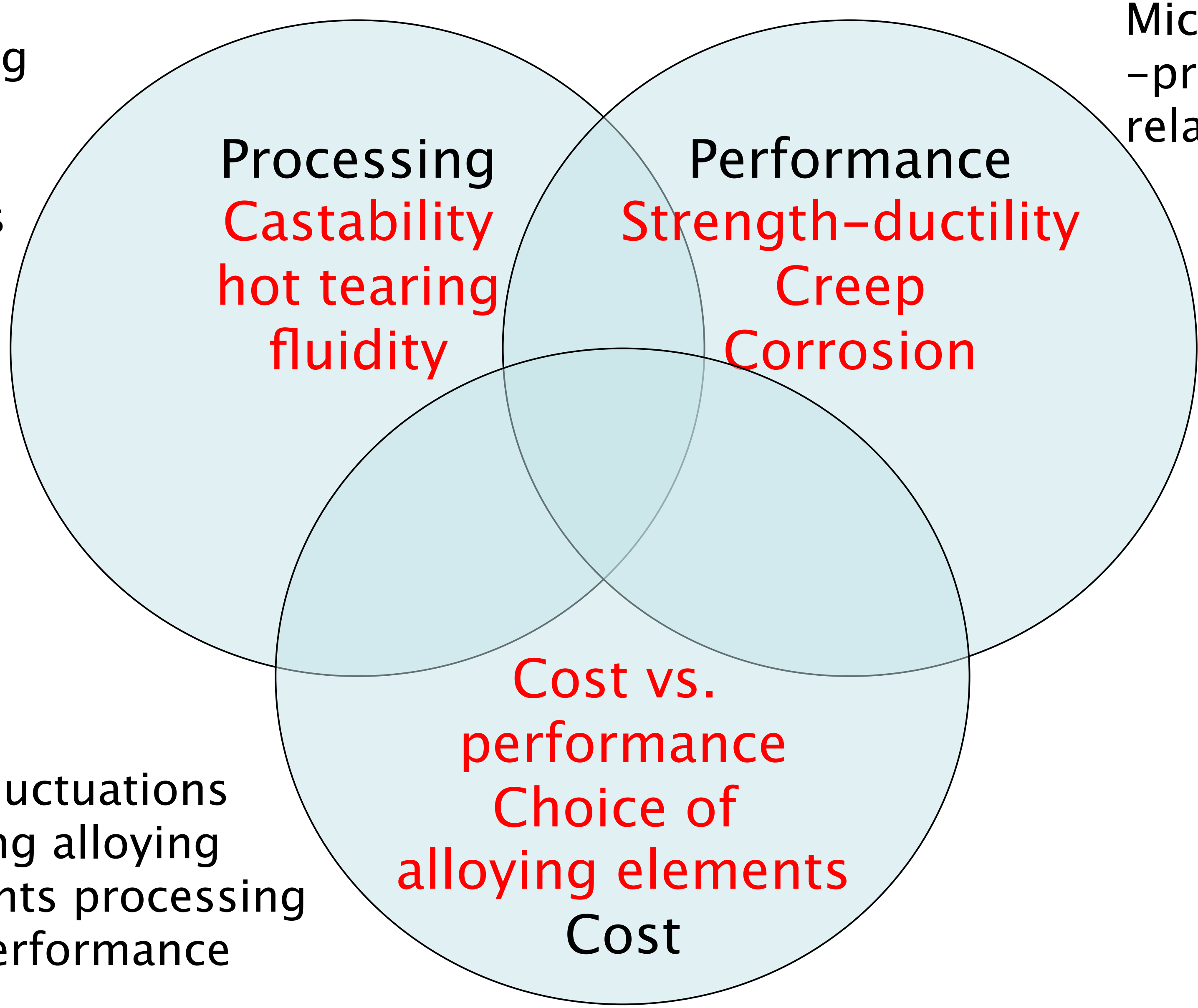
- Lots!!!

- Alloy systems investigated
  - Mg-Al: main commercial system AM50/60, AZ91
  - Mg-Al-Sr,Ca,RE etc: some commercial alloys MRI alloys in particular, AXJ530, AJ62 (BMW engine block) but little take-up
  - Mg-Zn-Al(-Ca,RE) alloys such as AMlite
    Lots!!!
  -
  - Mg-Al-RE: current substantial growth and appear to be the alloys of
    Mg-Al: main commercial system AM50/60, AZ91
-

What makes a good commercial alloy?

Understanding
Hot tearing
Castability
Test methods
Models

Microstructure
-property
relationships



Cost fluctuations
Relating alloying
elements processing
and performance

Mg-Al alloys

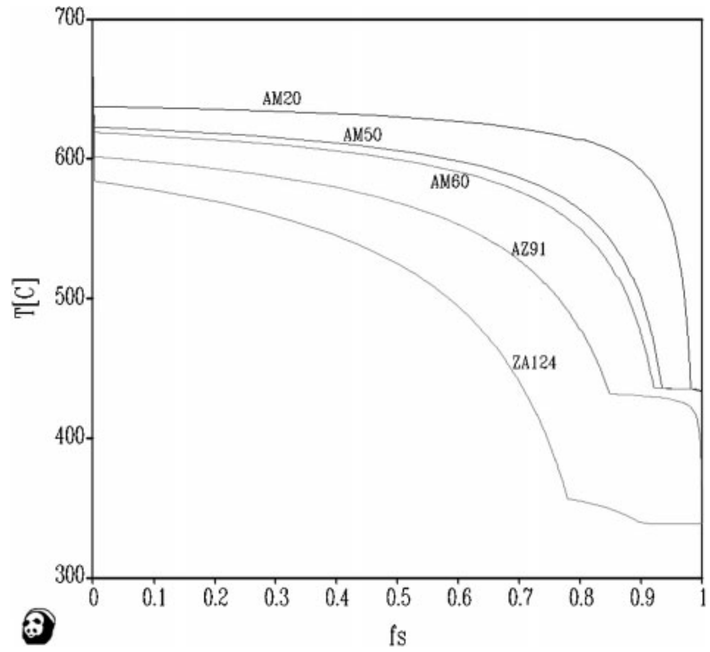
- Most successful commercial system
- Acceptable combination of strength, ductility and castability
- AM50/60: Mg-(5-6)Al-0.3Mn
  - Higher energy absorption, castability more limited
  - Examples: Instrument panels, steering wheels, seats
- AZ91: Mg-9Al-(0.5-1)Zn-0.3Mn
  - Excellent castability, good strength, ductility can be limiting in some applications
  - Housings, interior automotive components, electronic casings

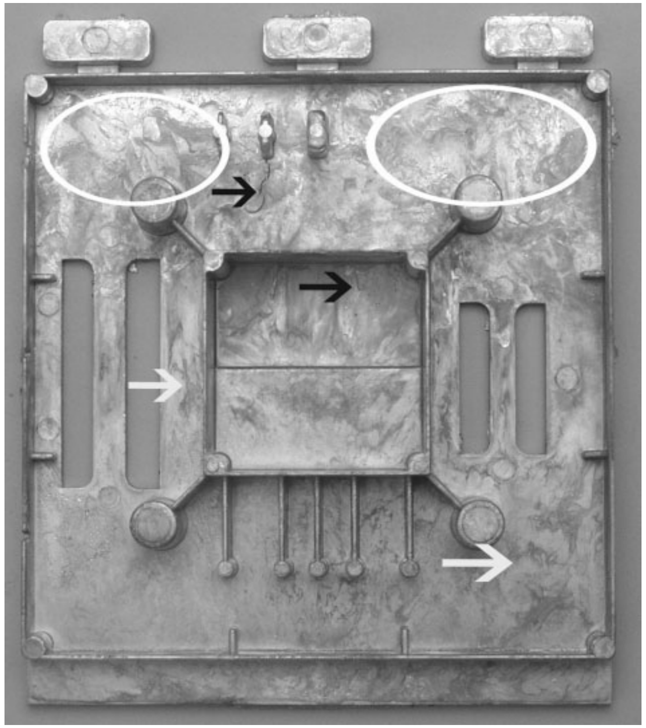
Meridian IP beam (AM60)

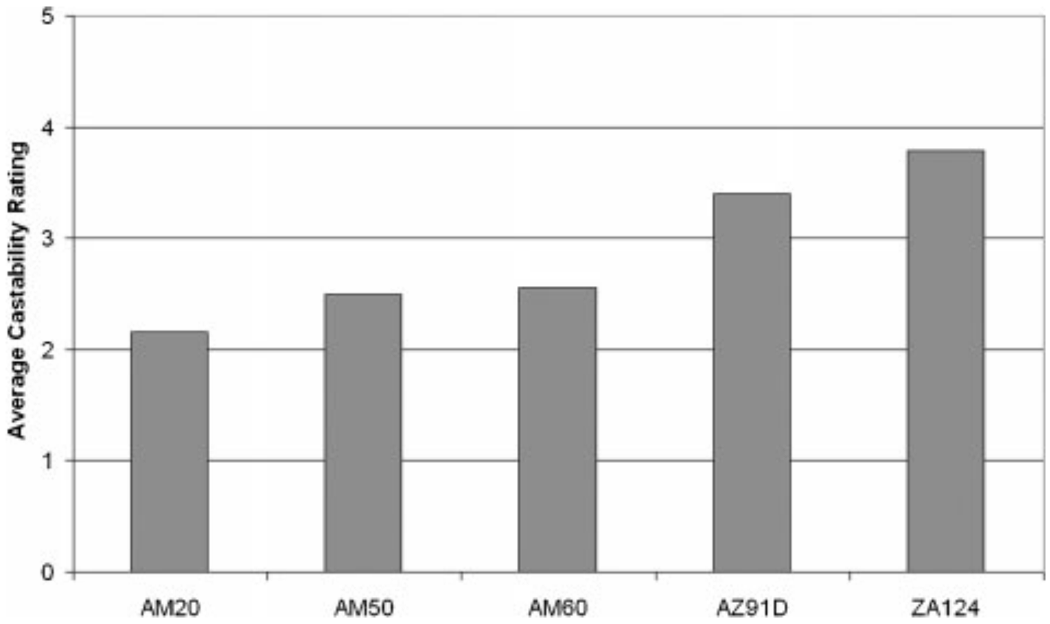
Camera housing

Mg-Al: castability

- Mg-Al alloys become more castable with increasing Al content
- Increasing Al content increases the amount of eutectic and increasing fluidity and decreasing feeding defects, e.g. hot tearing and porosity





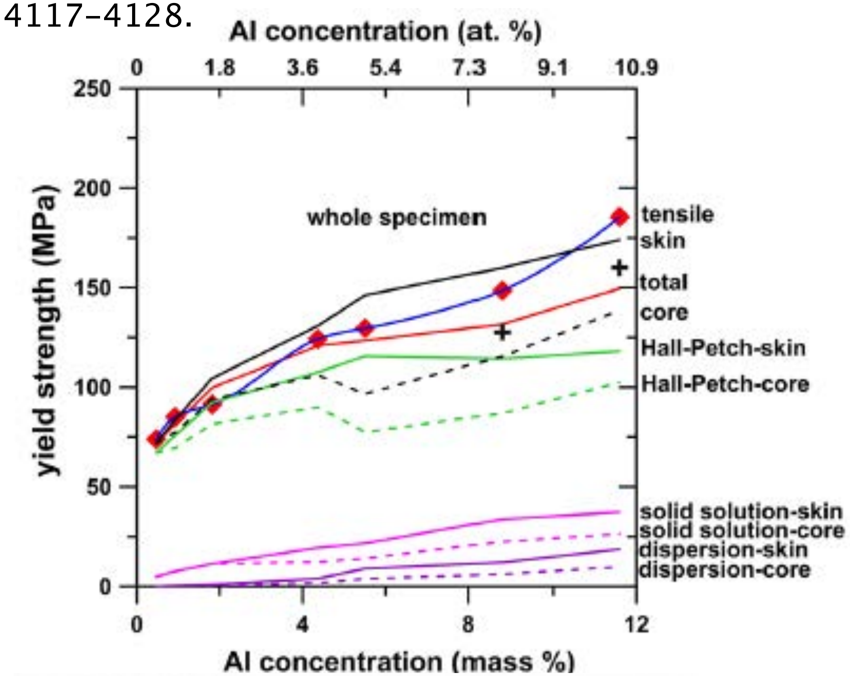


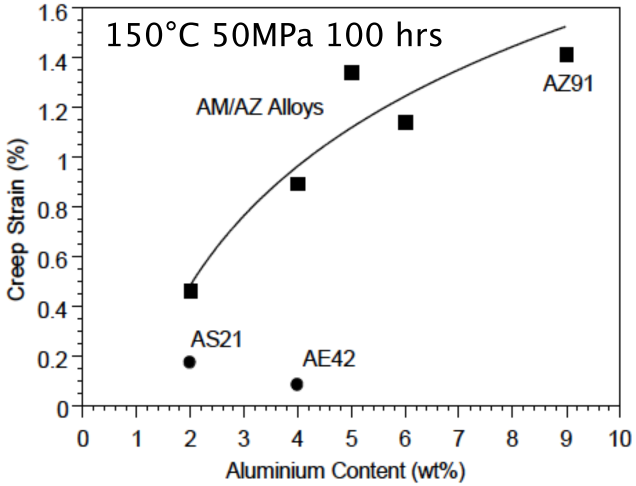
K. Strobel, M.A. Easton, V. Tyagi, M.T. Murray, M.A. Gibson, G. Savage, and T. Abbott: *Int. J. Cast Met. Res.*, 2010. vol. 23(2), pp. 81–91.

Mg-Al: strengthening (Cáceres, Dargsuch, Easton, Zhu, Gibson etc)

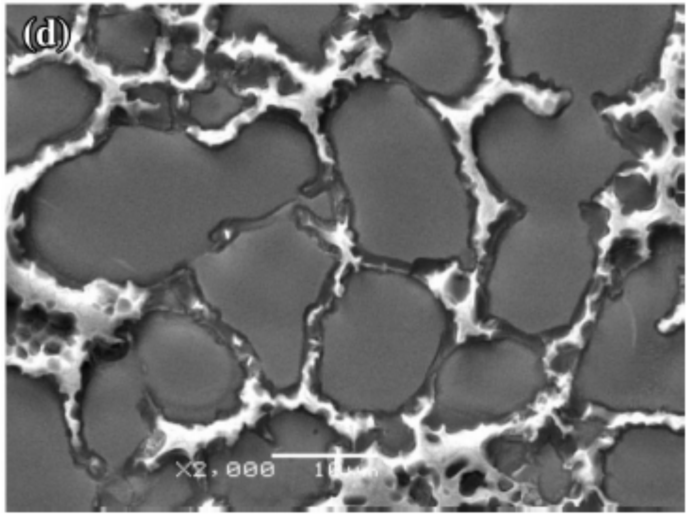
- Big steps in understanding strength, creep, corrosion, microstructure
- We now know:
  - grain size and intermetallic volume and morphology are critical to the strength-ductility relationship
  - Corrosion is almost entirely dependent on controlling the impurity levels
  - Increased Al in matrix is bad for creep but still not completely sure why

K.V. Yang, et al: *Metall. Mater. Trans. A*, 2014. vol. 45(9), pp. 4117-4128.





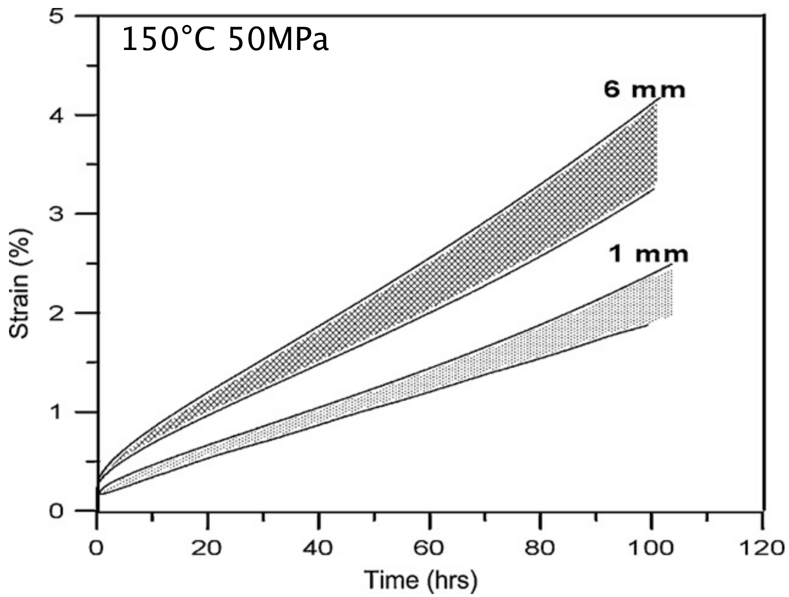
T.B. Abbott and M.A. Easton: *Mater. Forum*, 2001. vol. 25, pp. 181-201.



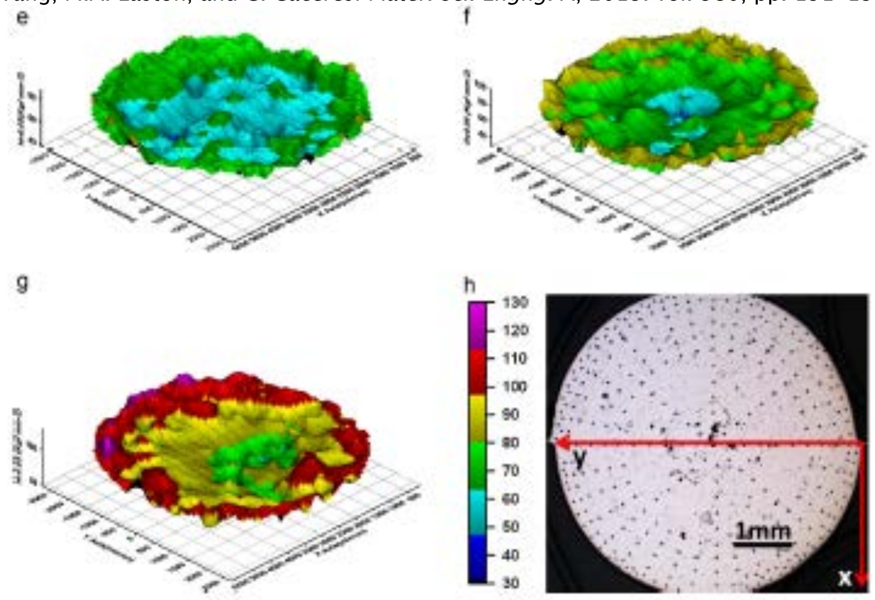
Mg-Al: Importance of the skin (Caceres, Yang)

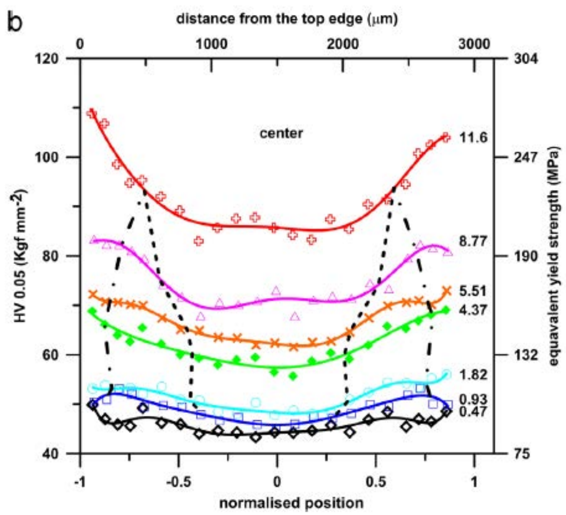
K.V. Yang, M.A. Easton, and C. Caceres: *Mater. Sci. Engng. A*, 2013. vol. 580, pp. 191-195.

- HPDC Mg alloys have a refined skin
- Its fine grain size is very important for strengthening
- Skin increases with solute content
- Microplasticity approaches to the skin
- Also affects creep properties (thinner samples with increased proportion of skin)



M. Dargusch, M.A. Easton, S.M. Zhu, and G. Wang: *Mater. Sci. Engng. A*, 2009. vol. 523, pp. 282-288.



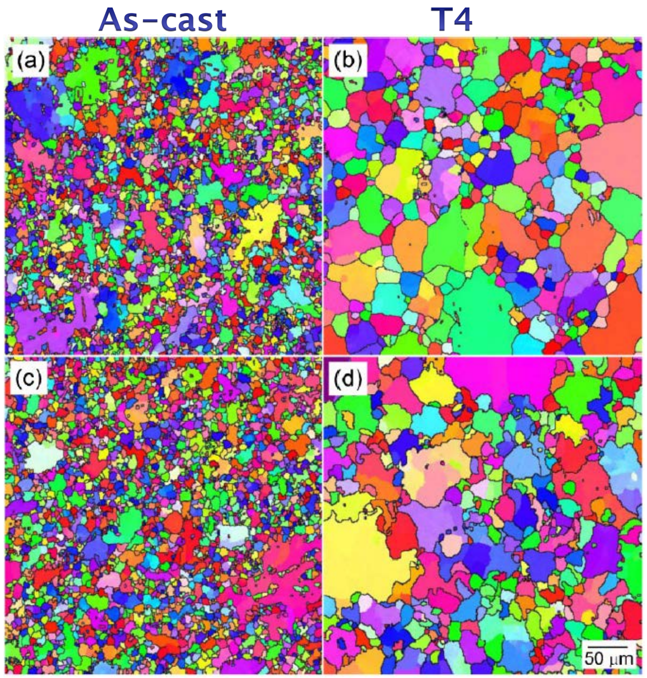


K.V. Yang, C.H. Cáceres, and M.A. Easton: *Mater. Sci. Engng. A*, 2013. vol. 580, pp. 355-361.

Mg-Al: Problem of heat treatment (at least for HPDC) (Zhang, Easton, Zhu, Gibson, Savage)

Specimen	0·2% yield strength/MPa	Tensile strength/MPa	Elongation/%	Average grain size/μm
As cast	167·0±1·5	241·0±8·2	5·3±0·9	7·6
T4	103·5±0·6	256·3±8·4	10·2±1·0	23·3
T5 (11 h)	162·0±1·5	238·7±2·2	3·8±0·2	7·7
T6 (11 h)	143·3±1·6	237·3±7·4	4·0±0·4	22·9

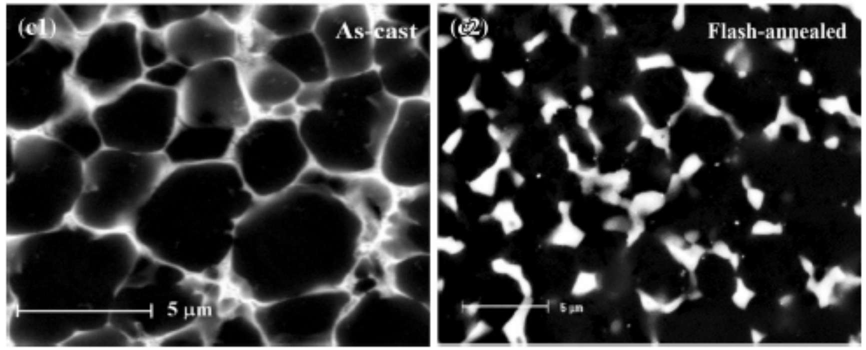
- AZ91 – no improvement in strength with heat treatment even T5
- Main issue is grain growth (even in skin with ageing and no solution treatment)
- Also noticed that vacuum casting had only a small effect on the properties of the alloys



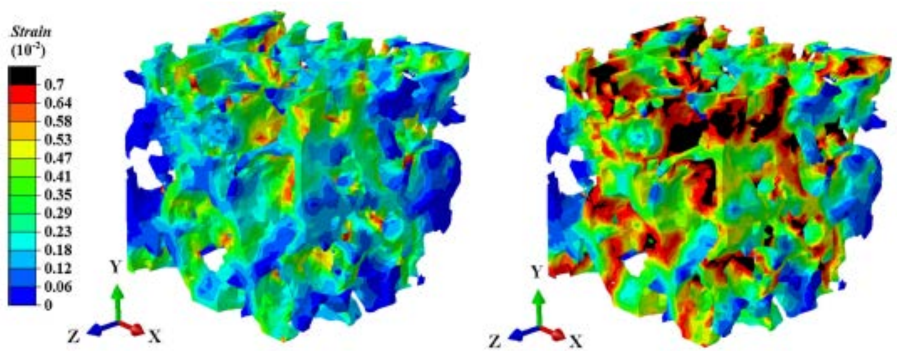
X.J. Wang, S.M. Zhu, M.A. Easton, M.A. Gibson, and G. Savage: *Int. J. Cast Met. Res.*, 2014. vol. 27(3), pp. 161–166.

Importance of the intermetallic network (Zhang, Caceres et al)

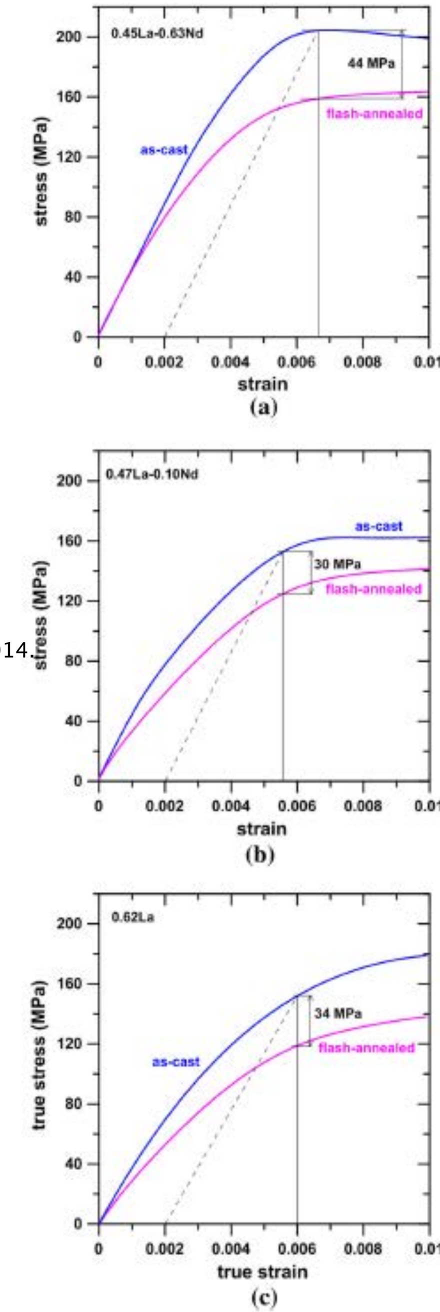
- Mg-RE alloys (low solubility) showed a substantial reduction in strength with morphology change in the intermetallic after heat treatment
- FEA modeling indicated this was due to the break-up of the intermetallic network
- Explains the difference between the predictions and measurements in Mg-Al alloys



B. Zhang, S. Gavras, A.V. Nagasekhar, C. Caceres, and M.A. Easton: *Metall. Mater. Trans. A*, 2014, vol. 45(10), pp. 4386-4397



Mg-0.65La



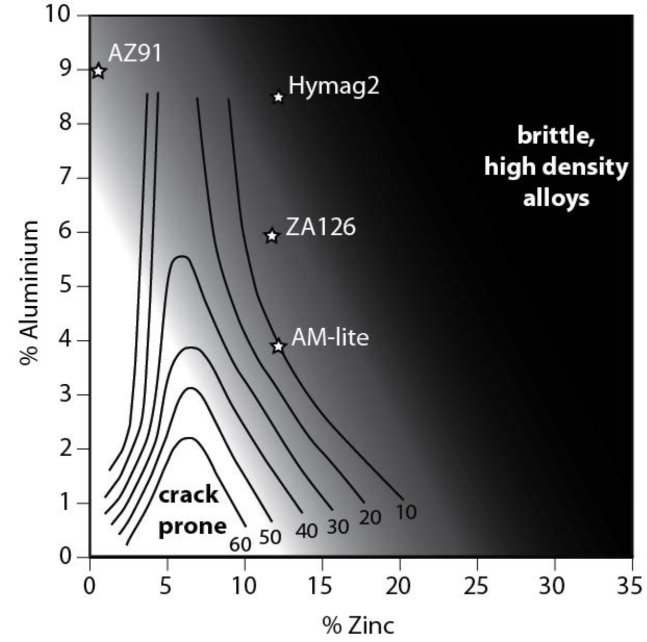
Mg-0.45La-0.63Nd

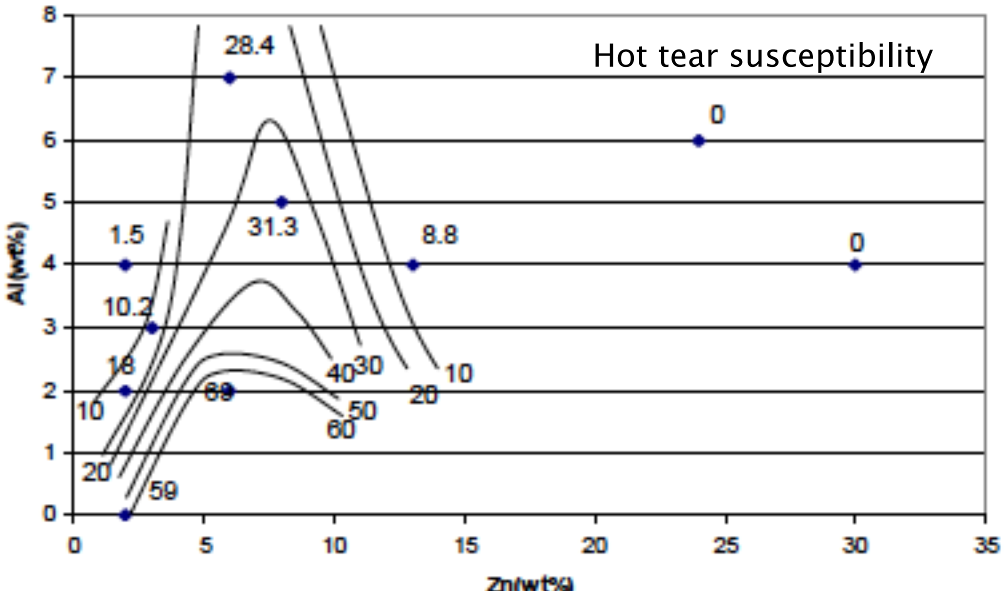
Mg-0.47La-0.10Nd

Mg-0.65La

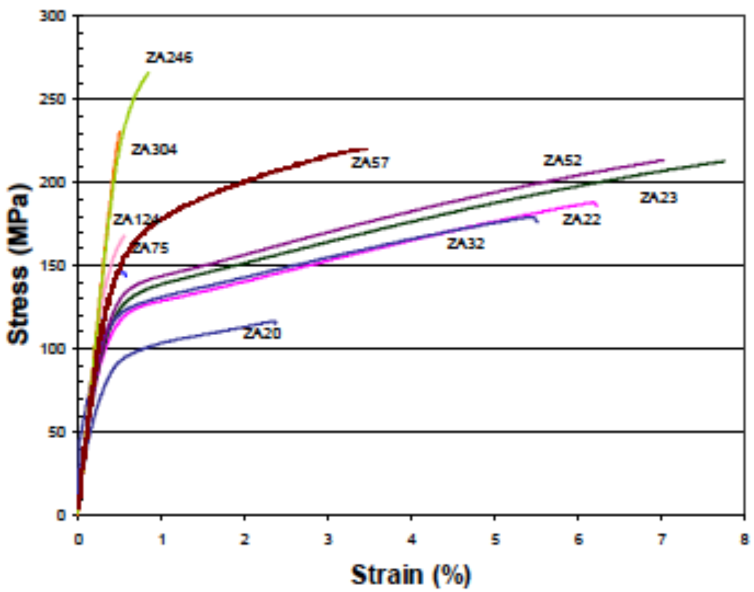
Mg-Zn-Al alloys (Abbott, Nie, Easton, Savage)

- Huge amount of interest and promise
- Best overall castability of all the alloys that we have cast due to low temperature eutectic
- However, this leads to too much brittle intermetallic and limited ductility
- Usable alloys can be found in the ZA12(4-8) range and are being used commercially (limited)
- Thin walled castings are where these alloys are best



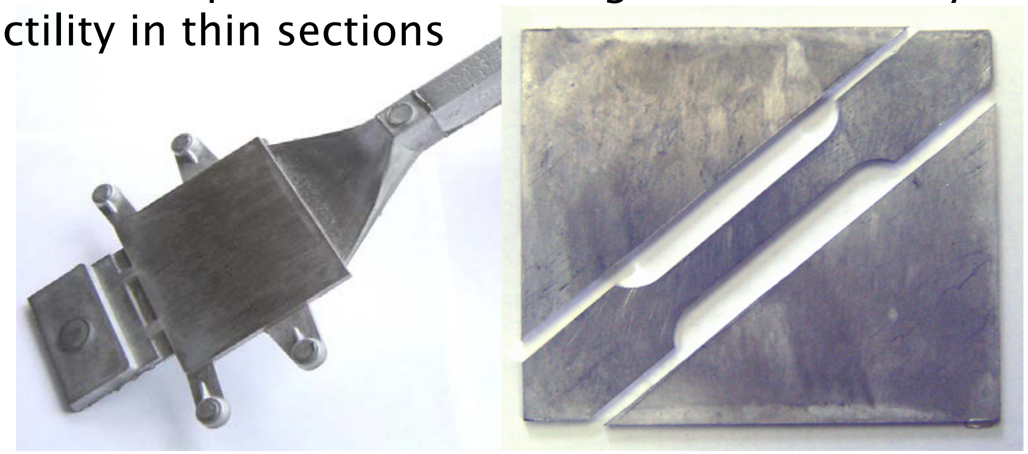


Easton, M.A., et al. in Magnesium Technology 2008. 2008. New Orleans LA: The Metals, Minerals and Materials Society. p. 323-328.

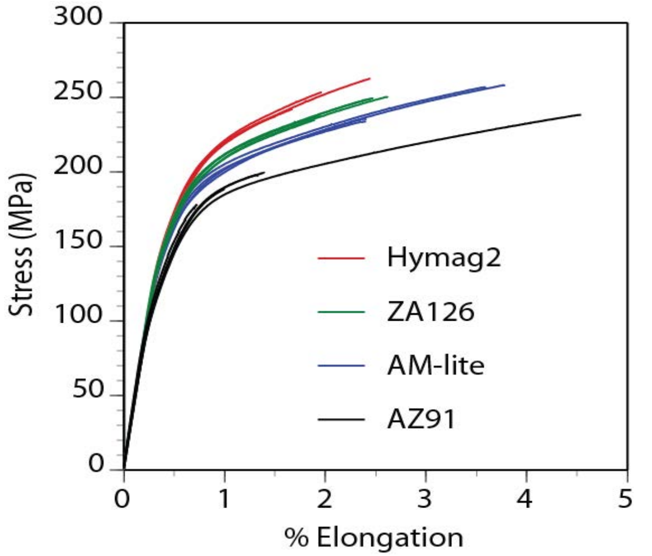


Tensile Properties from Die Cast Plates

AM-lite composition chosen to give best ZA alloy ductility in thin sections



Tensile specimens cut from 2mm thick plate



	% elong.	0.2% PS	TS
AZ91	1.8*	155	200
AM-lite	3.0	175	245
ZA126	2.3	183	244
Hymag2	1.7	191	245

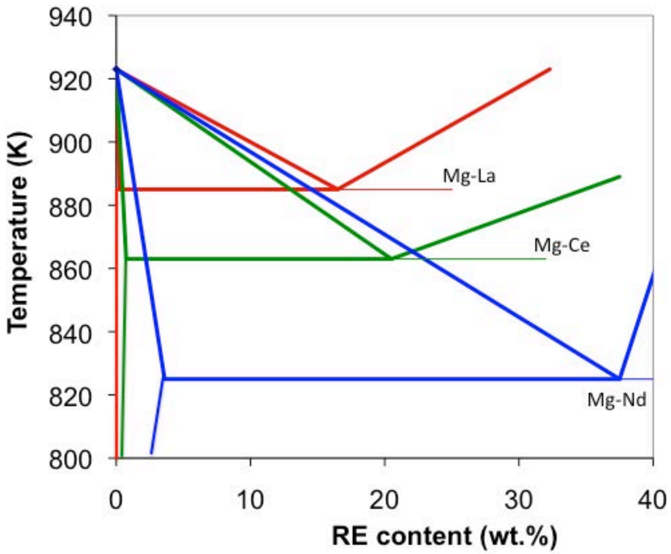
Average of 5, Stresses in MPa

* Lower average ductility of AZ91 due to poorer filling of thin plate

- ZA124 (AM-lite) gives good ductility in thin sections but low resistance to hot tearing
- ZA129 (Hymag2) has good resistance to hot tearing but has low ductility
- ZA126 a compromise between hot tearing and brittleness limitations

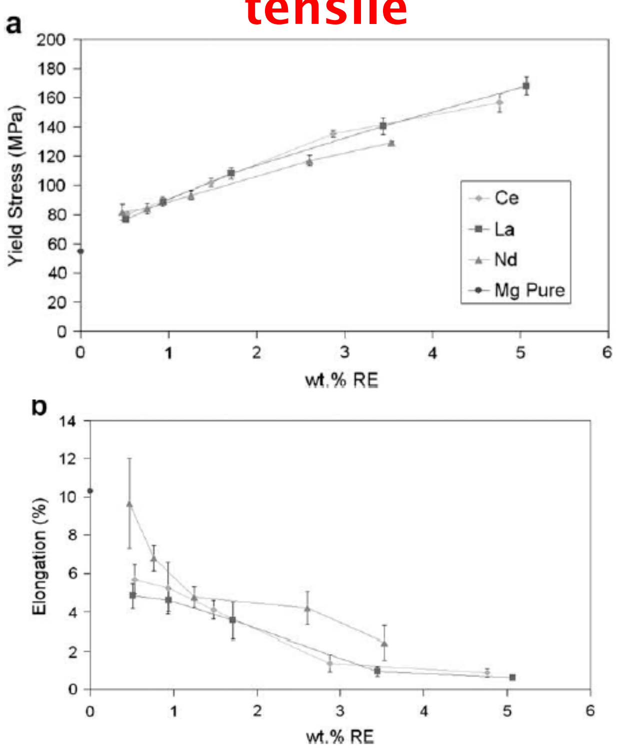
Mg-RE alloys (Gibson, Easton, Zhu, Nie, Abbott, etc)

- Most studied system in CAST
- Excellent/exceptional creep properties (better than Aluminium A380)
- Cost-castability-creep-tensile properties
- Getting the best combination of properties is not easy

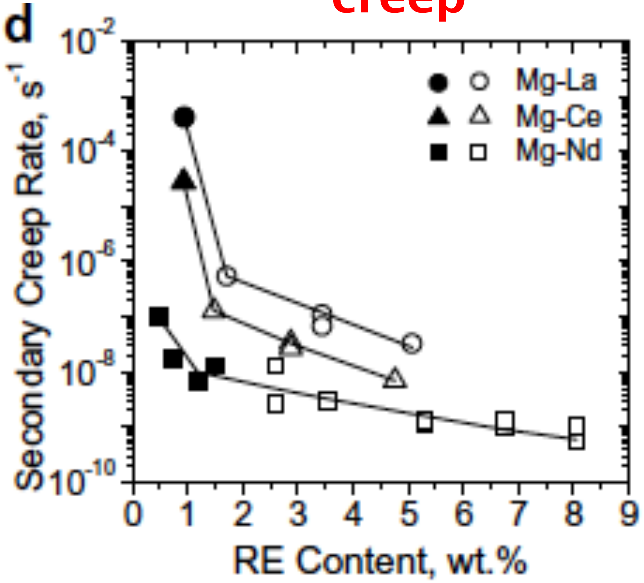


M.A. Easton, M.A. Gibson, S. Zhu, and T. Abbott: *Metall. Mater. Trans. A*, 2014, in press.

tensile

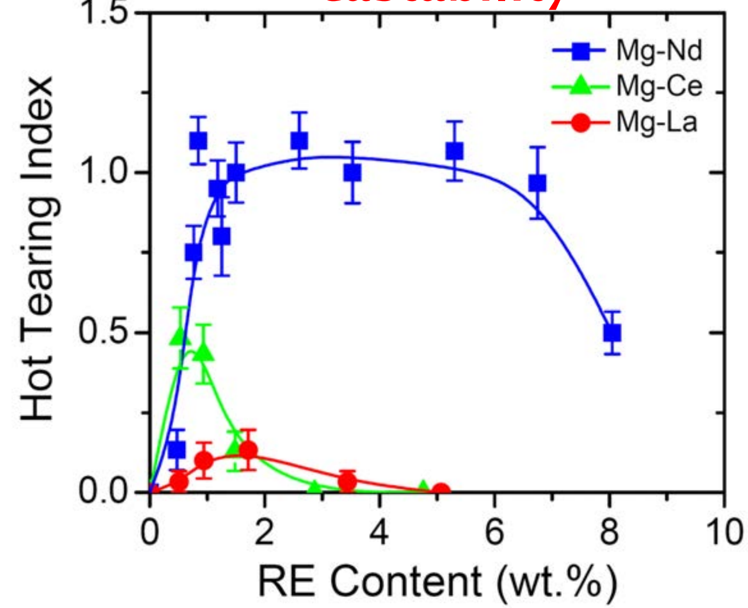


creep



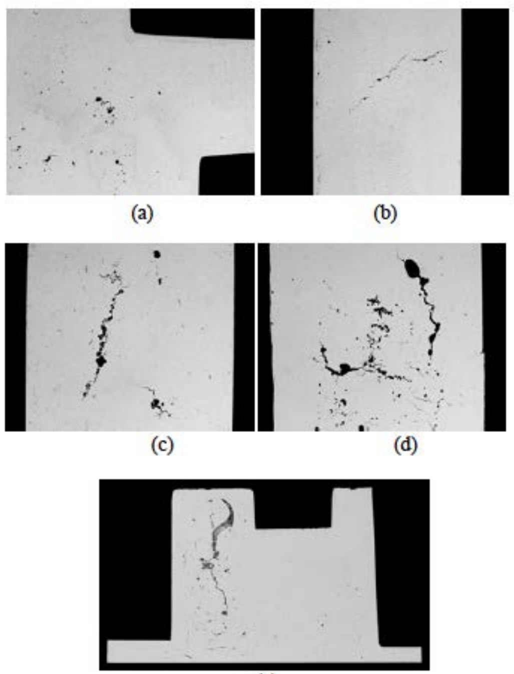
S.M. Zhu, M.A. Gibson, M.A. Easton, and J.F. Nie: Scripta Mater., 2010. vol. 63(7), pp. 698-703

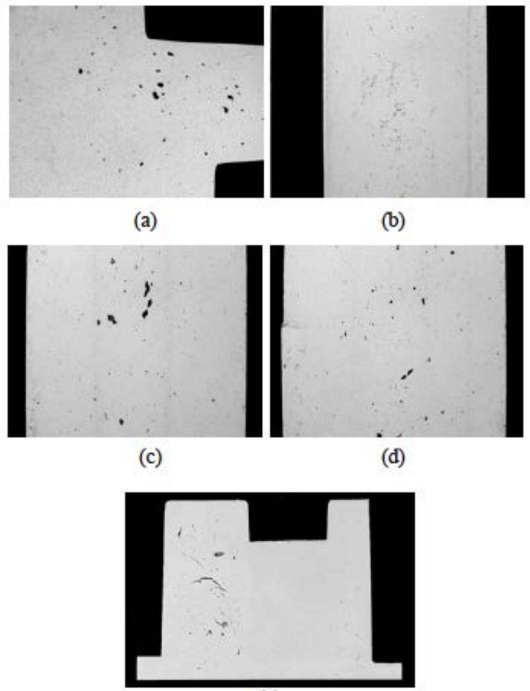
castability

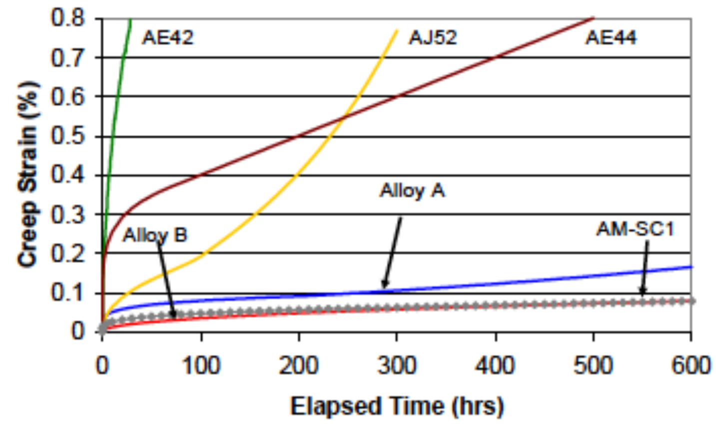


Designing a Mg-RE alloy (Gibson, Easton, Bettles)

- AM-HP2plus has been found to be the optimum (Mg-La-Nd/Y-Zn-Al-Mn)
- Start with a castable Mg-La alloy
- Add RE elements that are soluble and precipitate and don’t affect the castability too much
- Control the Al and Zn contents to optimize the creep properties of the alloys



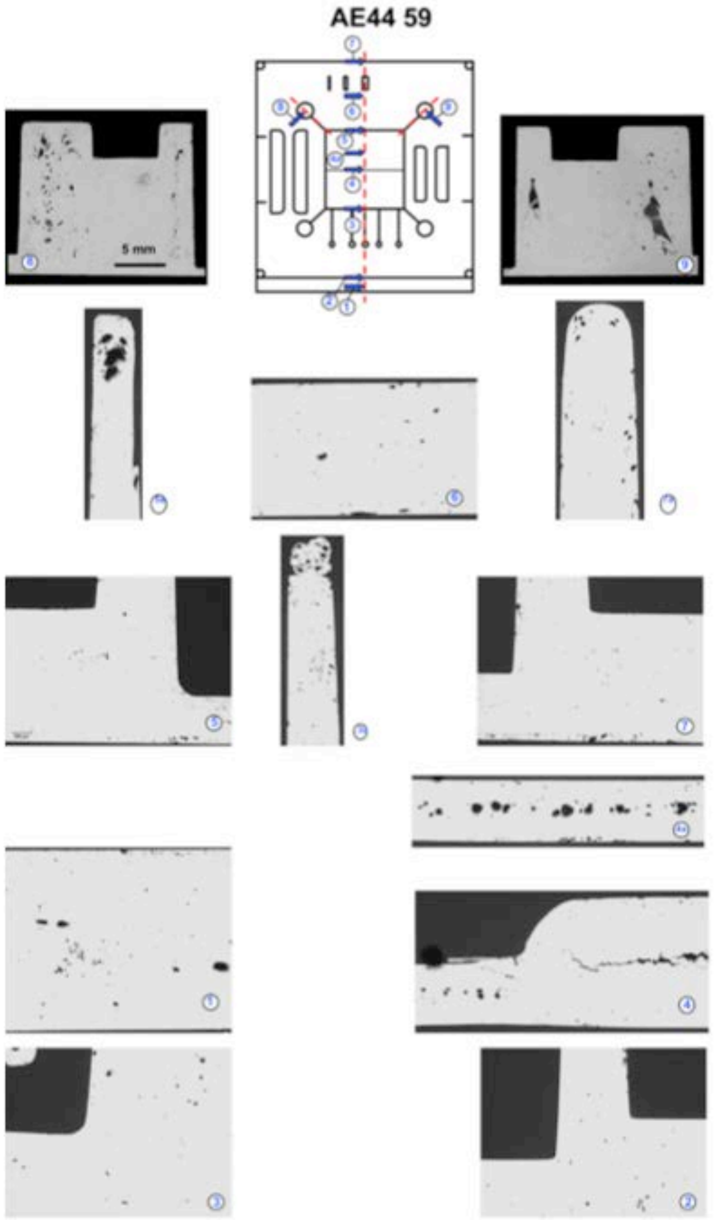




M.A. Gibson, M.A. Easton, V. Tyagi, M.T. Murray, and G.L. Dunlop, *Further improvements in HPDC Mg alloys for powertrain applications*, in *Magnesium Technology 2008*, M.O. Pekguleryuz, et al., Editors. 2008, The Metals, Minerals and Materials Society: New Orleans, LA. pp. 227-232.

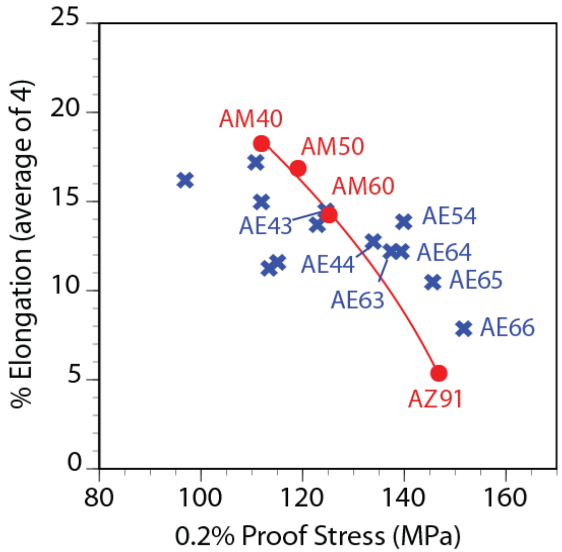
Mg-Al-RE alloys

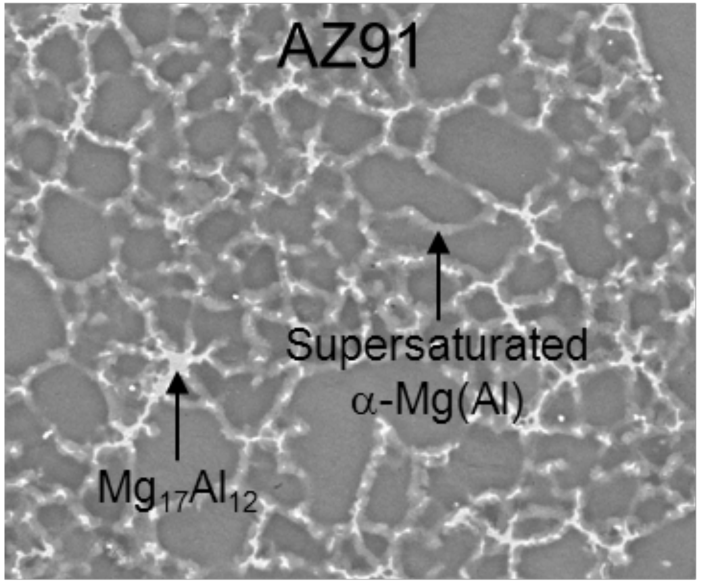
- Current Alloys – AE42 (some castability issues) and AE44 (excellent castability and properties but can they be improved?)

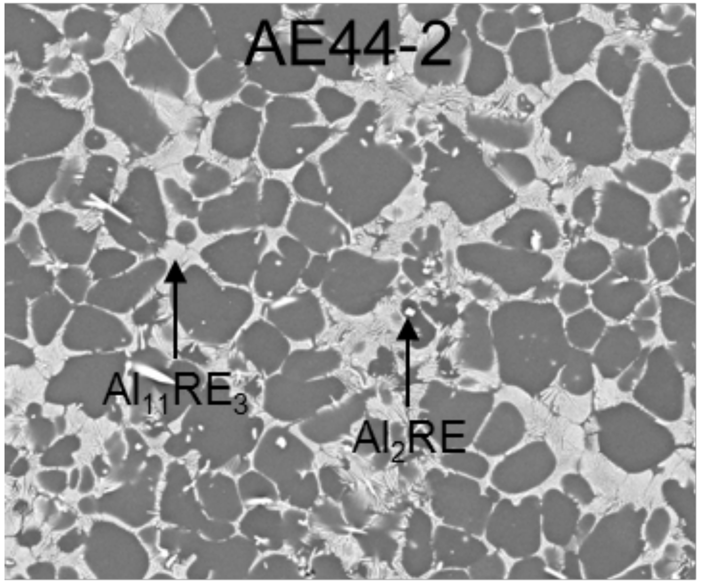


Mg-Al-RE alloys

- Higher strength – ductility combinations than Mg-Al, particularly at higher strengths
- Could be best structural alloys
- Eutectic is a fine fibrous type eutectic rather than a divorced/semi-divorced
- This could lead to the reinforcing by the intermetallic to increase strength without the continuous fracture paths

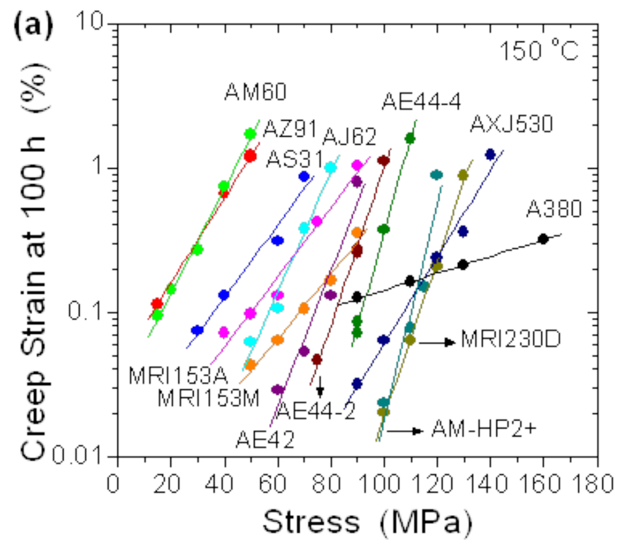


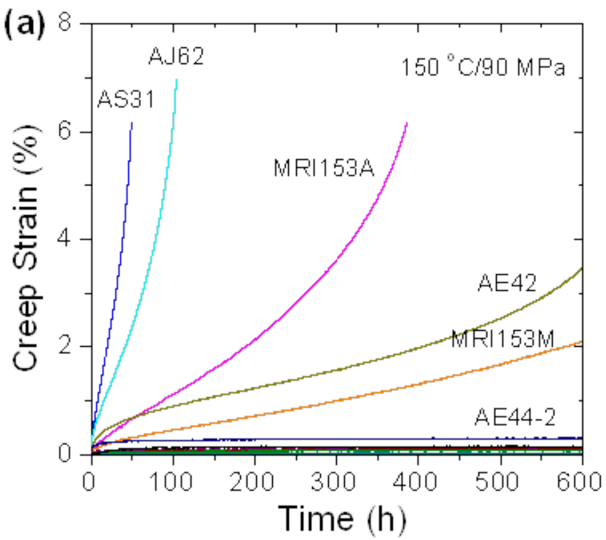


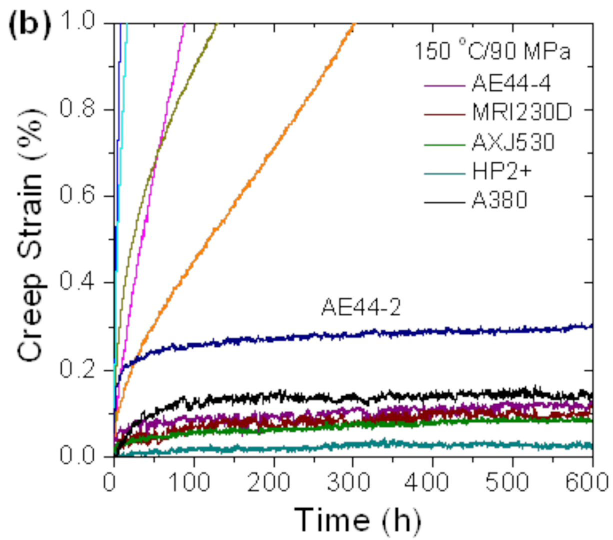


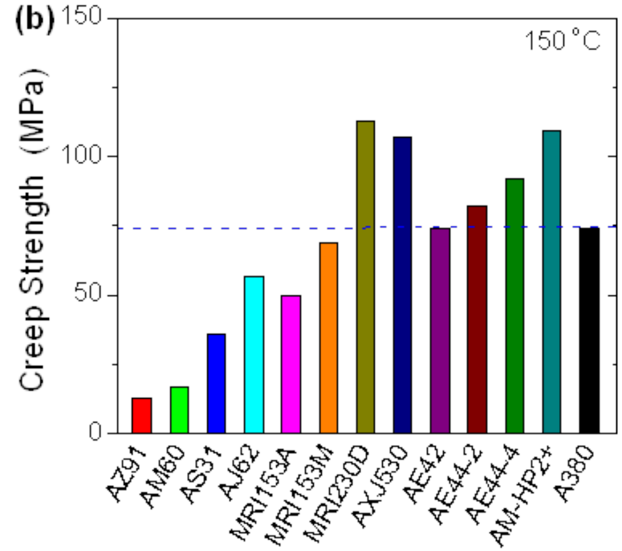
Mg-Al-RE alloys

- Good (but not best) creep resistance
- Reason for this still not completely clear
- Latest results show these alloys dynamically precipitate like other high creep resistant alloys, which contain Ca (MRI230D, AXJ530) or rare earths (HP2+)









What makes a good alloy system?

- 1. Good combination of castability and strength-ductility (essential requirement)
  - eutectic system with a non-continuous and well dispersed brittle phase is best (ductile phase is dominant in the eutectic)
  - This means that alloys can be made that are closer to the eutectic (good for castability)
- 2. Creep (for another talk in detail)
  - Grain boundary strengthening is important (but not that important)
  - Strengthening of matrix phase is important
  - Best creep resistant alloys contain soluble elements with low diffusivity (precipitation during creep without overageing)
- 3. Corrosion (for another talk in detail)
  - Keep impurity levels low. Control with Mn
  - General corrosion of most of the ‘commercial alloys’ is sufficient
  - Galvanic corrosion is still the most critical issue
  - Coatings are important
- 4. Cost
  - Price stability and supply is as important as cost but don’t use too much expensive stuff

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