MAGNESIUM ALLOY DEVELOPMENT

Science within constraints

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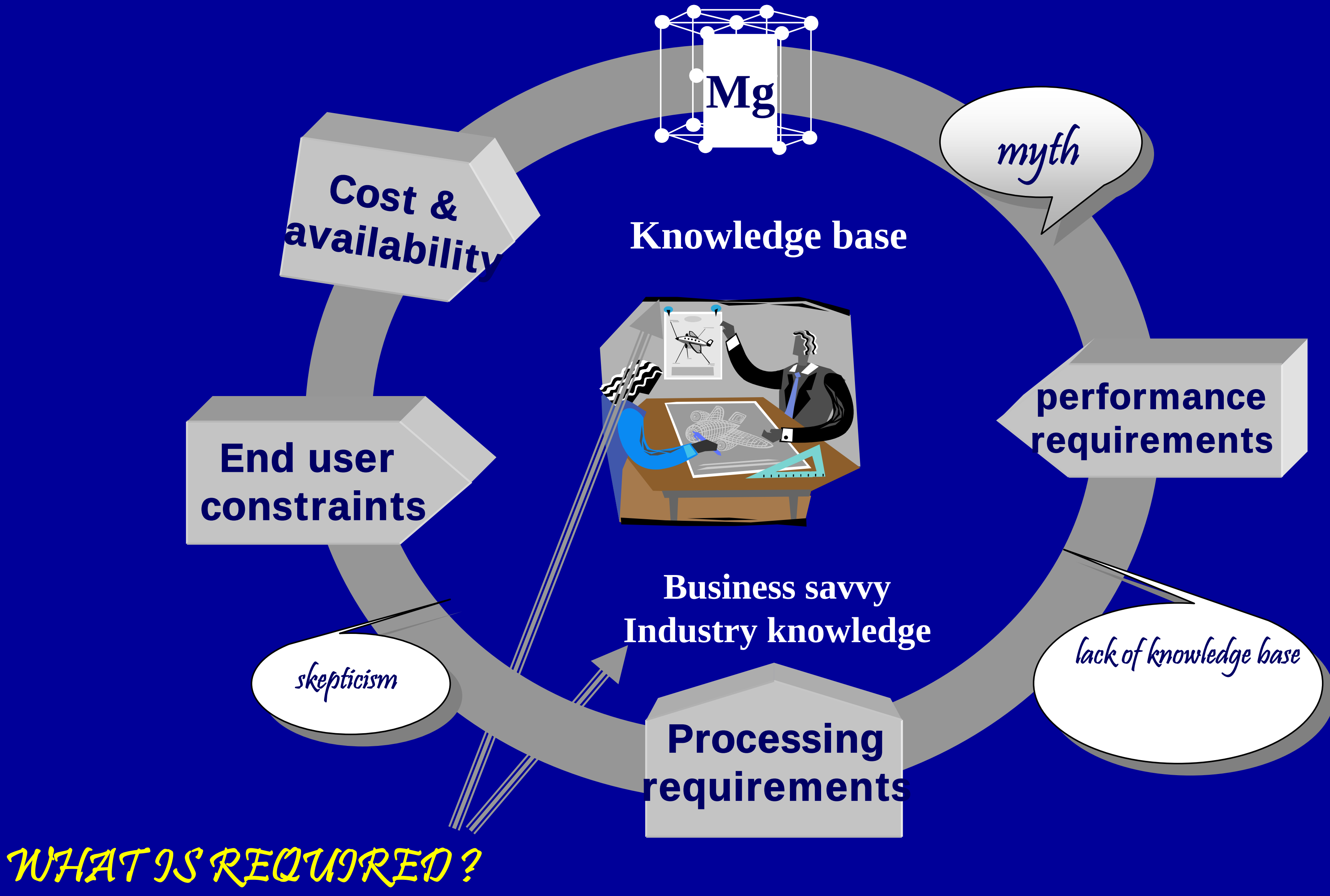
Magnesium alloy development challenges the scientist & engineer 360^0

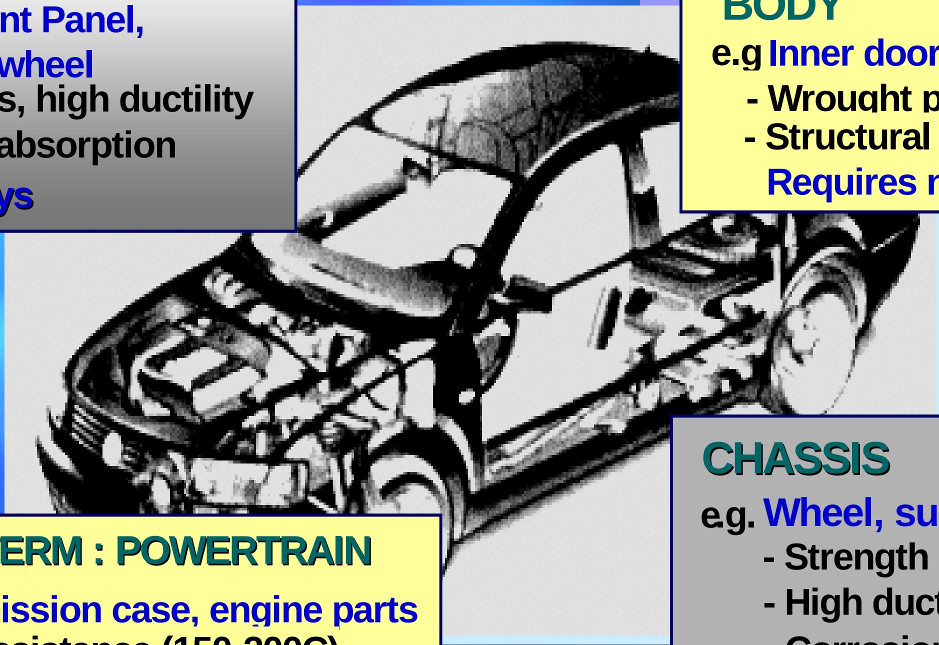


Mg ALLOY REQUIREMENTS IN AUTOMOTIVE APPLICATIONS

CURRENT USE: INTERIOR COMPONENTS

e.g. Instrument Panel, steering wheel
- Stiffness, high ductility
- Energy absorption

AM alloys



MID-TO-LONG-TERM

BODY

e.g Inner door panel, pillar structures
- Wrought products (formability)
- Structural casting alloys (ductility)

Requires new alloys and processes

CHASSIS

e.g. Wheel, suspension arm
- Strength
- High ductility, fatigue
- Corrosion resistance

Requires new alloys

SHORT TERM : POWERTRAIN

e.. Transmission case, engine parts
- Creep resistance (150-200C)
- Yield strength
- Corrosion resistance
- Mg-Al-RE & Mg-Al-Si

Requires new alloys

ALLOY TYPES NEEDED IN THE SHORT-TO-MID-TERM

CASTING ALLOYS

- **Creep resistant (175 C or above)**
- **Improved castability (thin-walled)**

1990s-o-present

New challenges

WROUGHT ALLOYS

- **improved formability, rollability, workability at room temperature**
- **corrosion resistance**
- **low cost processes**

DEVELOPMENT OF Mg CREEP RESISTANT CASTING ALLOYS

BACKGROUND

- **1990s: potential use of Mg in the powertrain**
  North America: oil-pan, transmission case
  Europe: engine block and transmission case

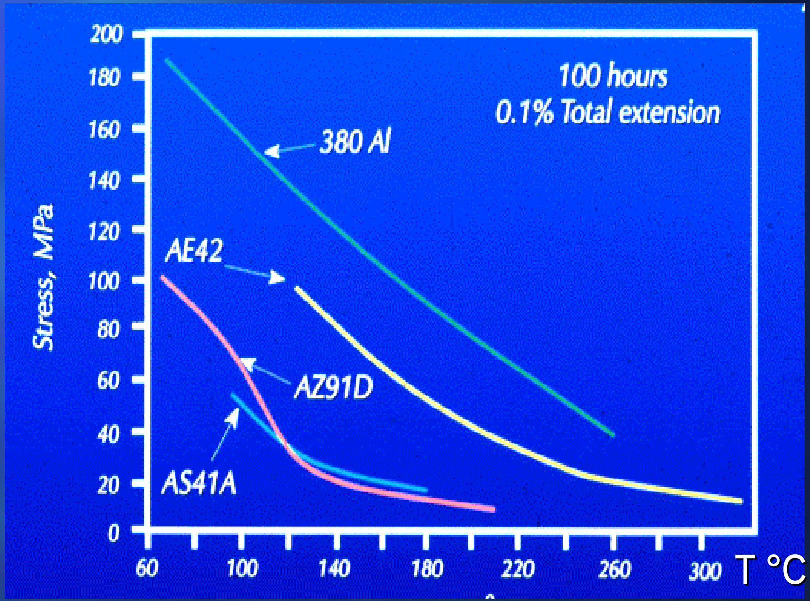
- **Requirements :**
Creep-resistance
and
tensile yield strength
at and above
150°C,
castability
and others….

DEVELOPMENT OF Mg CREEP RESISTANT CASTING ALLOYS

BACKGROUND

- Mg alloys have been traditional considered for die-casting (HPDC)
- Conventional alloys (Mg-Al, Mg-Al-Zn) HPDC alloys lose creep resistance above 120C.
- Traditional creep resistant alloys of Mg (HPDC) perform between 120-150C.
- Aerospace alloys (WE42): not die-castable; expensive

ALLOY	Creep resistance
TRADITIONAL ALLOYS	
AS41	medium
AS21	medium
AE42	good up to 150C
AEROSPACE ALLOYS	
WE42	High (200-250C)



- 1990s to 2003: alloy development activities in North America, Europe, Israel, Australia, China, Japan

COMMERCIAL AND NEW Mg CREEP RESISTANT ALLOYS (HPDC)

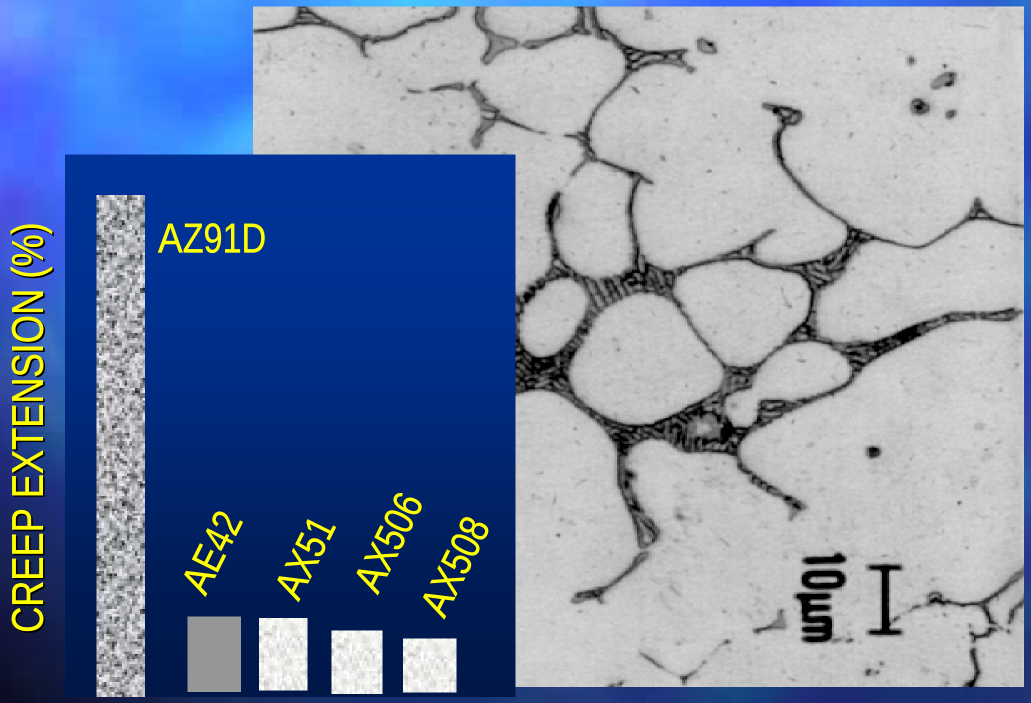
ALLOY	DESIGNATION	INVENTOR	STATUS / COMMENTS
Mg-Al-Si	AS41 (Mg-4Al-1Si) AS21 (Mg-2Al-1Si)	VW	Commercial
Mg-Al-Si (RE)	AS21x	Hydro Mag.	PATENTED
Mg-Al-RE	AE42 (Mg-4Al-2 RE)	Dow	Commercial
Mg-Al-Ca	AX51 {Mg-5Al-(.2-.8)Ca}	ITM	WO96/25529 (1995), PD*
Mg-Al-RE-Ca	AEX ACM522--(Mg-5Al-2RE-2Ca)	Nissan-UBE Honda	EP 0799901 A1 (1997) NK** EP 0791 662A1 (NK**)
Mg-RE-Ca (Mn)	EX {Mg-(2-5)RE-(0-1)Ca}	MEL	WO96/24701 (NK**)
Mg-Zn-Al-Ca	ZAX850	IMRA	US 5855697 (1999)
Mg-Al-RE-Ca (Sr)	MRI 153, MRI 230D	DSM-VW	US 6139651 (2000)
Mg-Al-Sr	AJ {Mg-(2-9)Al-(.5-7)Sr}	Noranda	US 6322644 (2001)
Mg-Al-Ca-Sr	AXJ {Mg-5Al-(2-3)Ca-0.07Sr	GM	US 6264763 (2001)
Mg-Al-Sr-Ca	AJX {Mg-(2-9)Al-(.2-.6)Sr-(.15-.3Ca)	Noranda	US 6342180 (2002)

* PD: public domain ** NK: status not known

Mg-Al-Ca ALLOYS BY ITM (INTERMAG)-1995-96

DATE OF APPLICATION / ORIGINATOR	COMPOSITION (wt%)						CLAIMS
	Al	Zn	Mn	RE	Ca	Si	
1996 - ITM Inc	2 - 6				0.1-0.8		Alloys with composition to give Al_2Ca precipitation good creep resistance (WO96/25529)

* *Source: J.F. King, "Development of Magnesium Diecasting Alloys," Magnesium Alloys and their Applications, B.L. Mordike, K.U. Kainer, Eds, Proc. Vol. Sponsored by Volkswagen……April 1998, p. 43*



CREEP EXTENSION (%)
150°C, 35 MPA FOR 200 HOURS

ALLOYS				
AX506	AX508	AX51	AZ91D	AE42
0.31	0.26	0.33	2.54	0.33

Very good properties but Castability issues

Mg-Al-Sr Alloys (Noranda)

2-10% Al, 1.2-7%Sr
One of the compositions commercialized in automotive engine block

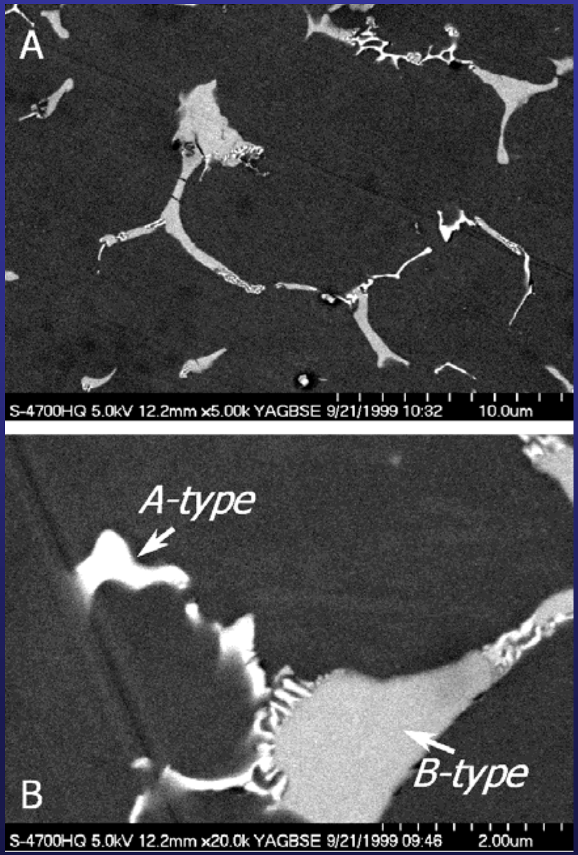
AJ52x
AJ62x

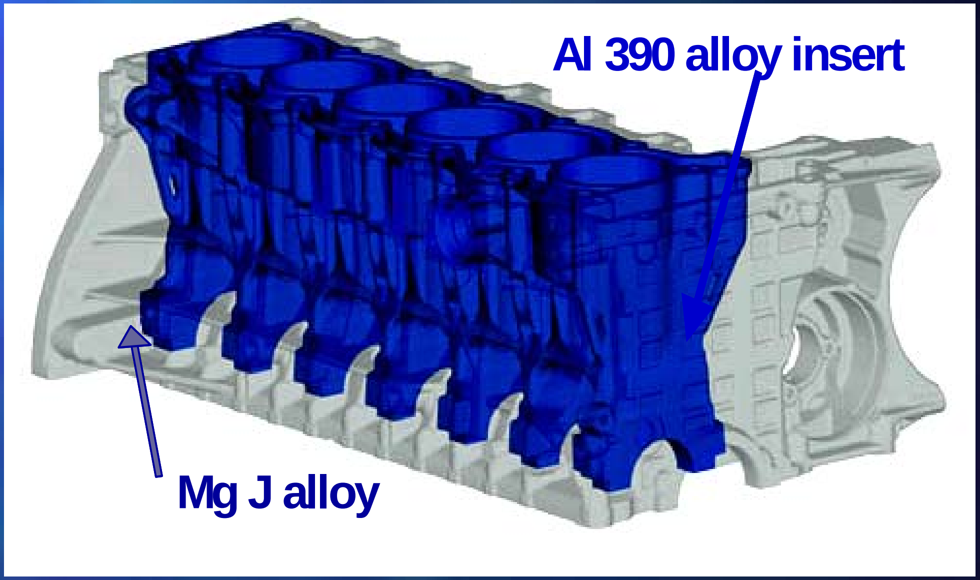
α-Mg and

Type A

Type B

intermetallics





BMW hybrid engine block

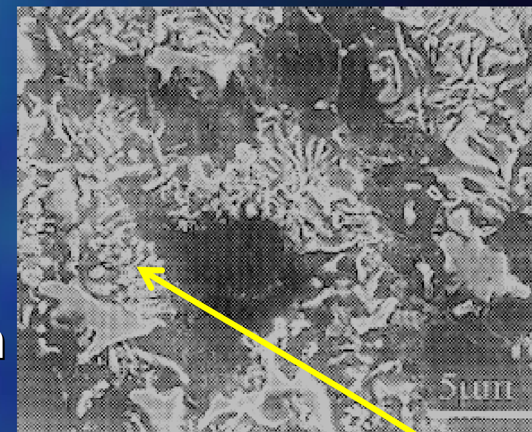
▪The scientific fall out

- Creep involves thermally activated recovery processes: dislocation motion, diffusion)

-To be prominent above 0.3 T_m of Mg and of the solute

- Mg alloys especially diecast alloys have different mechanisms at room to moderate temperatures and moderate stress regimes:

  Stress and/or thermally induced precipitation from the supersaturated primary phase (e.g. $Mg_{17}Al_{12}$), or through decomposition of intermetallics (in AE alloys) which facilitates grain boundary migration



Creep induced $Mg_{17}Al_{12}$ pptn

- Hence we need to prevent this type of pptn

- Use metallurgically stable precipitates in alloy design

- For higher temperatures: more strategies and alloy phase diagrams need to be developed.

Grain boundary migration

COMMERCIAL USE OF CREEP RESISTANT ALLOYS IN AUTOMOTIVE APPLICATIONS

1970s VW use of AS (Mg-Al-Si) alloys

1990s: Use of the Honda alloy (Mg-Al-RE-Ca) in oil-pan

Recent:

- Use of AS31 in transmission case
- Use of DSM (Mg-Al-Ca-Sr-RE) alloys in VW
- Use of the AJ (Mg-Al-Sr) alloys in the BMW engine block (in all 330 and 630 series coupe models)

Example of Alloy development project that led to commercialization

AJ alloy for automotive powertrain

- Importance of prior knowledge: Exposure to industry problems, issues (research inst.)

- Grasp of Performance requirements

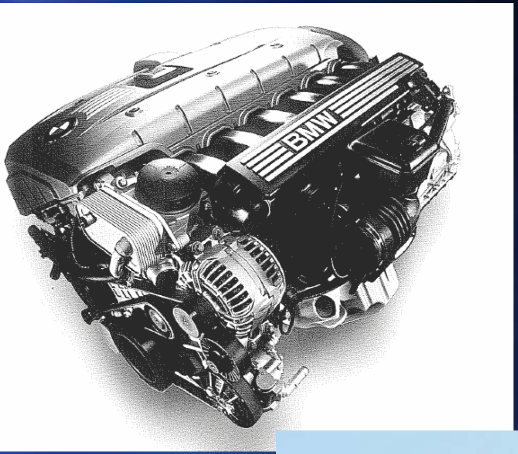
  - Creep resistance (tensile & compressive) up to 175°C (min creep rate)
  - Bolt-load retention up to 175°C (50% min)
  - Metallurgical / thermal stability
  - Tensile yield strength up to 175°C (100 MPa)
  - Fatigue resistance (fatigue limit at 175 ° C : 45 MPa min)
  - Ultimate tensile strength up to 175°C (130 MPa)
  - Salt-spray corrosion resistance (0.1-0.25 mg/cm^2/day)
  - Elongation (min 3% at room temperature)
  - Acceptable diecastability (comparable to AM or AE)
  - Acceptable cost (5-10 ¢over alloy prices)
  - Availability of raw materials
  - Alloy production (compatibility with plant processes)
  - Melt handling (oxidation, sludge formation)
  - Recyclability

Interdisciplinary team

Alloy development and patenting: 1 year
(creep resistance above 150C
Stable Al-Sr intermetallics,
control of Al/Sr ratio prevents $Mg_{17}Al_{12}$ pptn)

Evaluation & casting process development, recycling, reliability, supplier certification, carried out jointly with the alloy company and the automotive company (internal foundry) : 2 years

Commercial production: 4th year



- Important to maintain expertise in the form of institutes, clusters
- Important to maintain positive perspective on challenges

What did we learn as alloy developers ?

- **If we want alloy to be commercialized in the short-to-midterm**

  - We need to have a full grasp of the performance requirements, industry constraints, Creep behavior of Mg before we start alloy development projects

  - Build a multivalent team (mechanical, materials science and engineering, applications, production, manufacture, supply)

  - Materials scientist should sit very close to the industry, listen to them continuously

  - Once you have done that, do not listen to the traditional experts, follow your own train of thought. Be creative…

- **If we want to contribute to the knowledge base**

  - Study creep behavior and creep mechanisms, alloy phases, equilibria

NEW INTEREST: CREEP RESISTANT MAGNESIUM GRAVITY CASTING ALLOYS

1) COMMERCIAL AEROSPACE ALLOYS

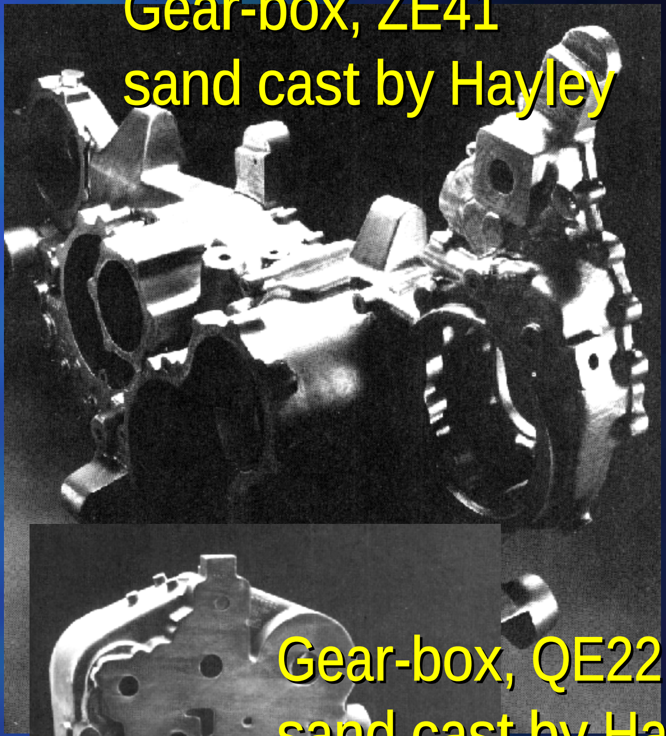
- Y, R.E. (Ce, Nd), Ag, Cu, Zn CONTAINING ALLOYS
- WE43, WE54, QE22, ZE41, ZC63, RZ5, ZRE1

2) NEW DEVELOPMENT FOR AUTOMOTIVE

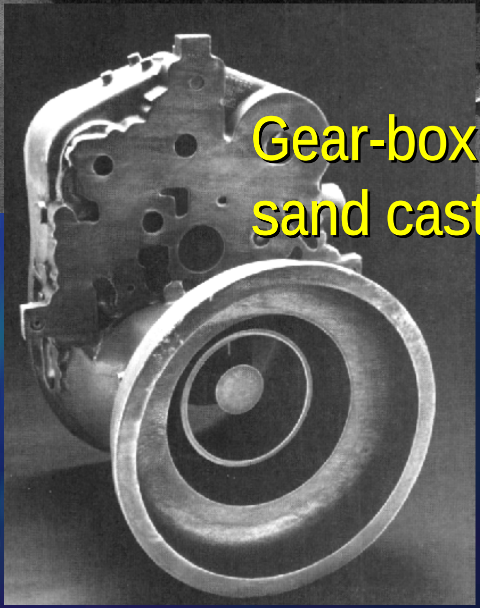
MEL and DSM ALLOYS

NEW Yttrium CONTAINING ALLOYS

Silicon CONTAINING EXPERIMENTAL ALLOYS



Gear-box, ZE41
sand cast by Hayley



Gear-box, QE22
sand cast by Hayley

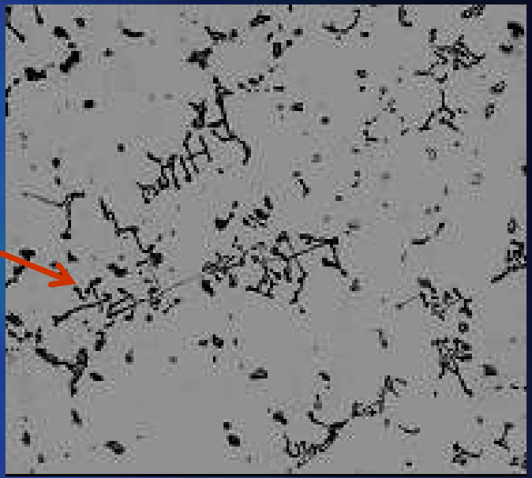
MAGNESIUM GRAVITY CASTING ALLOYS

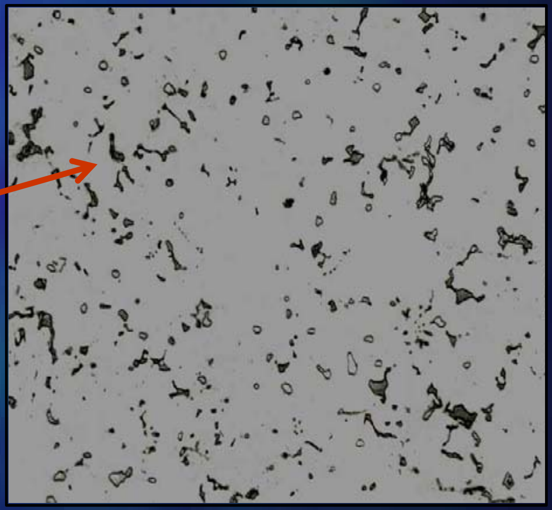
ALLOY	DESIGNATION	COMPANY / RESEARCHER	STATUS / COMMENTS
Mg-Y-RE	WE43, WE54	MEL	Commercial
Mg-Gd-Y-Zr	-	Prof. Kamado	Experimental
Mg-Y-Zn-Zr	-	Prof. Mordike	Experimental
Mg-Y-Zn-Nd-Zr	-	Prof. Mordike	Experimental
Mg-Zn-RE (Zr)	ZE41, EZ33, ZE62 MEZ (2.5RE, 0.5Zn)	MEL MEL	Commercial US 6193817 (2001)
Mg-Zn-Cu (Mn)	ZC63	MEL	--
Mg-Si (Al,Ca, RE) *hypereutectic*		S. Beer et al	Experimental
Mg-Al-Si-(Ca)	ASX410	M.Pekguleryuz et al	Experimental
	MRI 201S, MRI 201S	DSM-VW	--

MODIFICATION OF MG-Al-Si ALLOYS FOR GRAVITY CAST APPLICATIONS

MODIFICATION OF AS41 ALLOY WITH TRACE CALCIUM ADDITIONS (ITM, 1993)

- CHINESE SCRIPT MORPHOLOGY OF THE MG_2SI PHASE LEADS TOLOW DUCTILITY WHEN GRAVITY CAST
- WHEN DIECAST ALLOYS, THE HIGH FREEZING RATE REFINES THE CHINESE SCRIPT IMPROVING THE DUCTILITY
- O.05-0.1WT %Ca ADDITIONS TO GRAVITY CAST AS41 REFINES THE CHINESE SCRIPT AND IMPROVES THE DUCTILITY





NEW CHALLENGE : DEVELOPMENT OF NEW Mg CASTING ALLOYS FOR THIN-WALLED STRUCTURAL CASTINGS

Alloy compositions should lead to

- improved mold/die filling (low surface tension, low viscosity, appropriate freezing range, low liquidus)

- Improved ductility

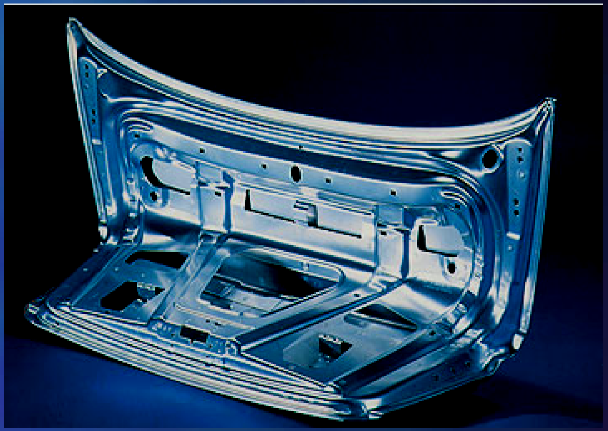
Challenges:

- Fluidity
- Melt cleanliness
- As-cast microstructure
- Hot-tearing
- Thermal properties

NEW CHALLENGE : DEVELOPMENT OF NEW WROUGHT Mg ALLOYS

Alloy compositions should lead to

- formability, workability at moderate temperatures below 400C
- strength and formability at room temperature
- corrosion resistance
- mass production at low cost
- viable thermomechanical processing for sheet
- viable forming technology for extrusions
- viable joining



Challenges:

- HCP crystal structure of Mg
- High critical resolved shear stress of non-basal slip systems below 250C
- Lack of in depth understanding of deformation mechanisms in Mg alloys
- Lack of industry-research cooperation and international programs in this field
- Only one or two viable sheet alloys (AZ31)
- Moderate corrosion resistance of wrought alloys
- High cost of sheet production

CURRENT : Mg ALLOY DEVELOPMENT RESEARCH IN CANADA

MCGILL UNIVERSITY

- CRD ON Mg SHEET (Prof. S. Yue)
- CRD ON MULTICOMPONENT ALLOY SYSTEMS (Prof. R. Gauvin)
- INDUSTRIAL RESEARCH CHAIR IN AUTOMOTIVE LIGHT METALS AND ADVANCED Mg MATERIALS (Prof. M. Pekguleryuz) (wrought alloys, phase diagram studies)

ECOLE POLYTECHNIQUE DE MONTREAL

- CRD ON ALLOY PHASE EQUILIBRIA (Prof. A. Pelton)

CONCORDIA UNIVERSITY

-ALLOY PHASE EQUILIBRIA (Prof. M. Medraj)

CANMET-MTL

-MG SHEET, ALLOY PHASES