Progress of Research and Development of Magnesium alloys on New Energy Vehicles in China

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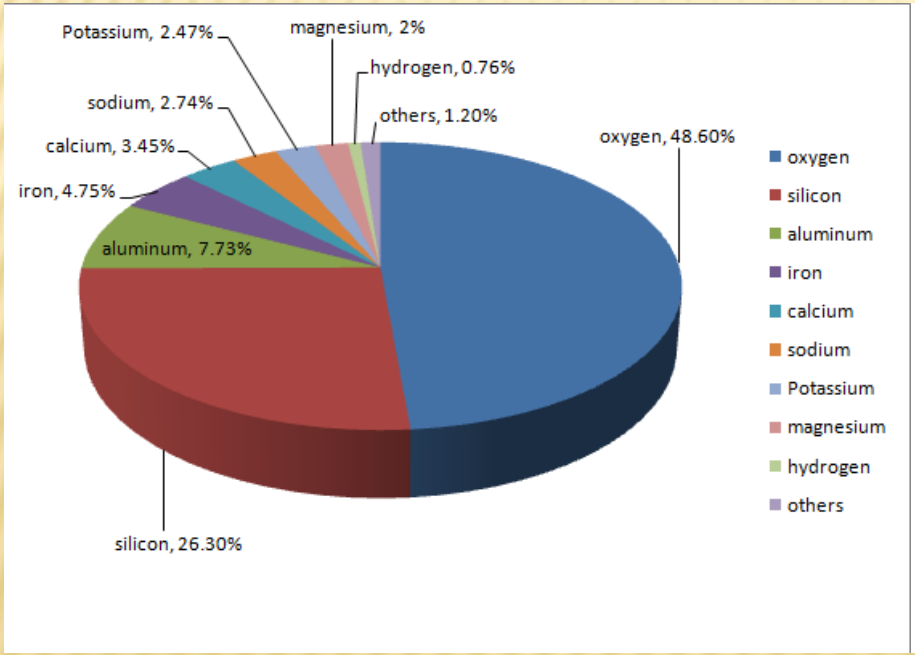
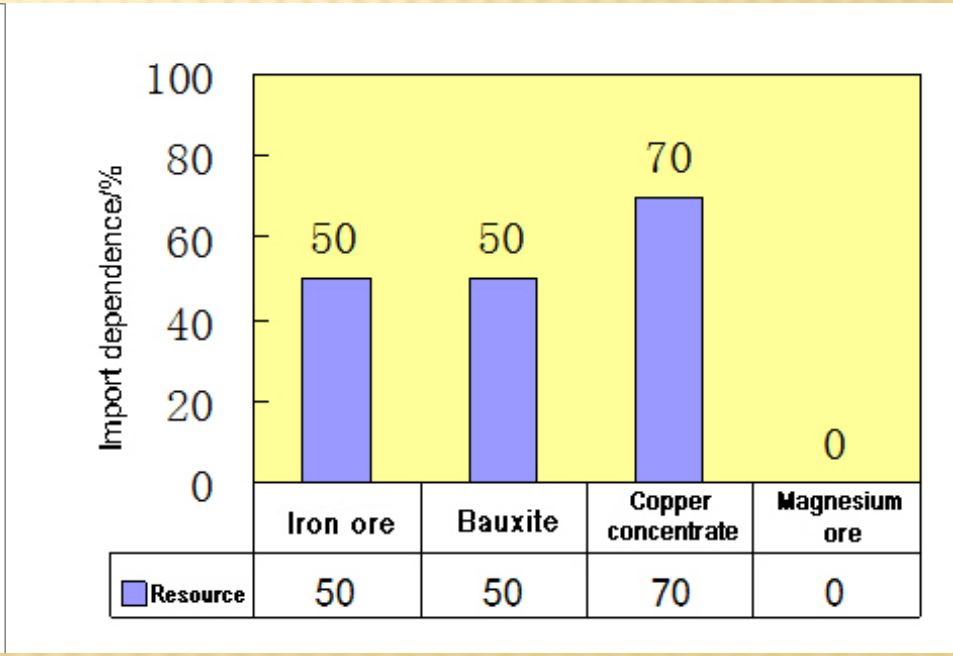
Outline

- **Research Background**
- **Magnesium smelting technology**
- **New Magnesium alloys development**
- **Fabrication Technologies of Magnesium alloys**
- **Evaluation Methods of Magnesium**
- **Development of Typical Magnesium components**
- **Integrated Application of Magnesium Components**
- **Development of Mg electric bus boy**
- **Challenges Faced with the Application of Mg**

Research Background—Rich in natural resoures

- Magnesium is rich in natural resources
- China is a major producer and exporter of magnesium.



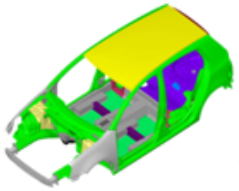


Research Background—Lightweight

The lightweight advantage of magnesium has been highly valued by the world wide. And China is no exception

SLC body structure concept

SuperLightCar
VOLKSWAGEN AG

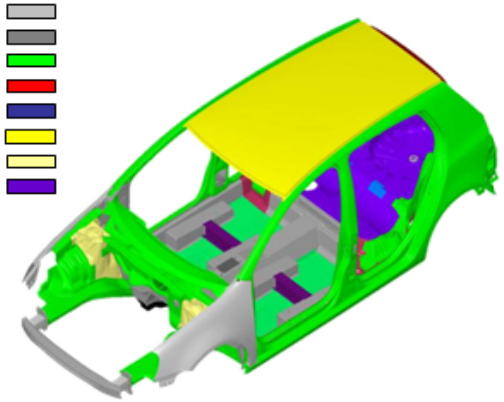


Weight reduction: ~30%

Additional part costs: < 5,0 €/kg

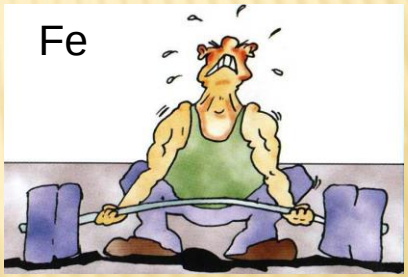
Highlights:
- Mg-Strut tower (die cast)
- Mg-Roof
- Hot formed steel door aperture
- FR plastic roof cross beam
- FR plastic rear floor
- Al-Casting rear longitudinal
- Polymer reinforced seat cross-member

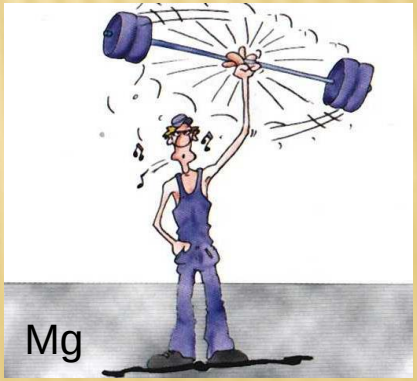
High strength steel
Hot-formed steel
Aluminium sheet
Aluminium cast
Aluminum extrusion
Mg-sheet
Mg-diecast
Fibre reinforced plastic



Material Mix:

Steel parts weight:	approx. 50 %
Al parts weight:	approx. 35 %
Mg parts weight:	approx. 8 %
Plastic parts weight:	approx. 7 %





Research Background— Enviroment Protection

In October 2016, The Society of Automotive in China released “the technology roadmap for energy saving and new energy vehicles” .
To fulfill the Energy-efficiency goal the technique roadmap require that:

- To the year of 2020, the application of magnesium alloy in a single car must exceed 15Kg
- To the year of 2025, the application of magnesium alloy is 25Kg
- To the year of 2030, the application of magnesium alloy is 45Kg.

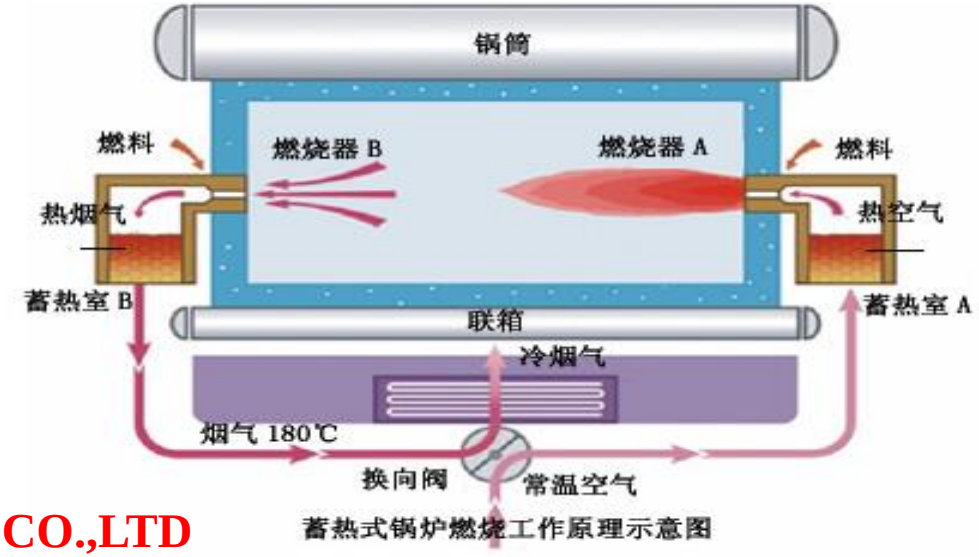
	2020	2025	2030
Magnesium alloy	**The magnesium consumption per vehicle is 15 kg**	**The magnesium consumption per vehicle is 25 kg.**	**The magnesium consumption per vehicle is 45 kg.**

Magnesium smelting technology

☐ Vertical tank reducing furnace heat accumulation combustion technology

- ✓ Developed a novel heat accumulation combustion vertical tank reducing furnace.
- ✓ The energy consumption was significantly reduced due to the compact structure of the furnace and high density tank of the combustion chamber

Standard coal consumption: less than 4.5 tons per ton Mg

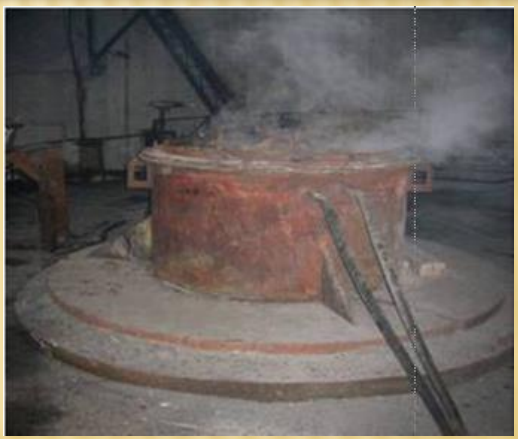


蓄热式锅炉燃烧工作原理示意图

Magnesium smelting technology

- Bottom slag removal technology
- Recovery and purify technology of the smelting waste
- Low grade smelting waste vacuum distill technology

Has been widely used in magnesium smelting industry and greatly increases Mg smelting efficiency



Magnesium alloys development

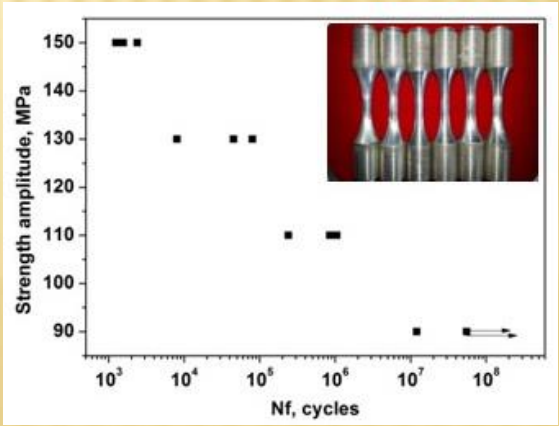
■ Fatigue-resistant cast magnesium alloy

- Magnesium alloy: Mg-8Zn-0.5Al-0.5Cu-0.5Mn; Mg-8Zn-1Al-0.5Cu-0.5Mn ; Mg-6Zn-1Al-0.5Cu-0.5Mn
- After two-stage aging, the mechanical properties: $\sigma_b \geq 300MPa$, $\sigma 0.2 \geq 205MPa$, $\delta \geq 10\%$.
- Fatigue property: Mg-8Zn-1Al-0.5Cu-0.5Mn alloy, the fatigue strength is higher than 90MPa (5×10^7)

Mg-8Zn-1Al-0.5Cu-0.5Mn Mechanical properties of alloy at room temperature

Alloy	Status	$\sigma_{02}(MPa)$	$\sigma_b(MPa)$	Extensibility（%）
Mg-8Zn-0.5Al-0.5Cu-0.5Mn	T6	213. 0	312. 6	10. 9
Mg-8Zn-1Al-0.5Cu-0.5Mn	T6	228. 0	328. 0	14. 7
Mg-6Zn-1Al-0.5Cu-0.5Mn	T6	208. 3	309. 1	10. 9

Fatigue performance test results of Mg-8Zn-1Al-0.5Cu-0.5Mn alloy



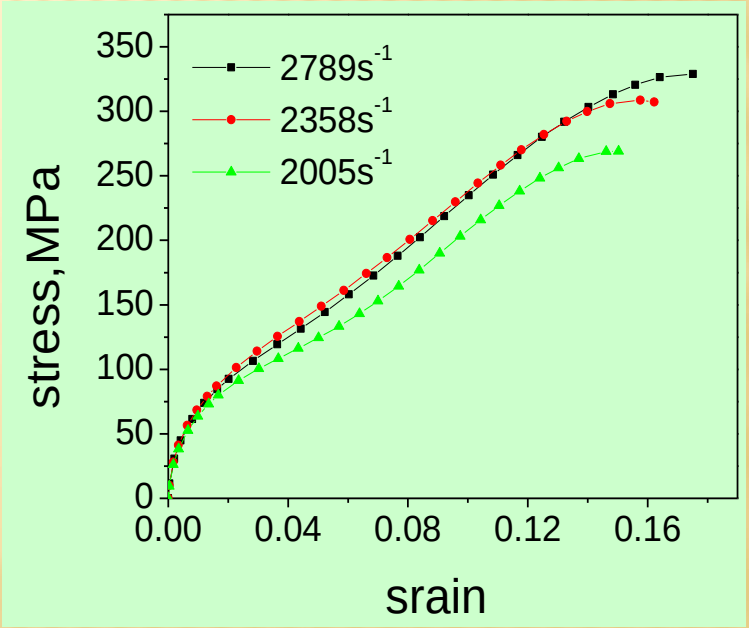
Magnesium alloys development

Impact-resistant cast magnesium alloy

The developed Mg-4Zn-3Y-0.3Zr alloy, after T4 or T6 treatment, the static mechanical properties: $\sigma_b \geq 250MPa$, $\sigma_{0.2} \geq 170MPa$, $\delta \geq 15\%$, and at high strain rate (The strain rate is $500 \sim 4000s^{-1}$), $\delta \geq 10\%$, and the performance meets the requirements of the assessment index.

Mg-4Zn-3Y Mechanical properties of heat-treated alloys				
Alloy	Processing state	$\sigma_{02}(MPa)$	$\sigma_b(MPa)$	δ_5（%）
Mg-4Zn-3Y-0.3Zr	T4	162.4	231.5	14.3
	270℃ aging	181.6	254.2	15.5
	320℃ aging	178.7	250.3	15.7

Impact compression-strain curve of Mg-4Zn-3Y-0.3Zr alloy (as cast)



Magnesium alloys development

High plasticity magnesium alloy

- Several low-cost and high plasticity deformation magnesium alloys have been developed
- The room temperature mechanical properties: $\sigma_b \geq 250MPa$, $\sigma_{0.2} \geq 190MPa$, $\delta \geq 20\%$.
- Mg-1Al-1Sn alloy is equivalent to AZ31 alloy in deformation ability. After hot extrusion at 300°C, the mechanical properties: $\sigma_b \geq 280MPa$, $\sigma_{0.2} \geq 230MPa$, $\delta \geq 22\%$.

High plasticity Mg alloys	Main feature	Market Price (ten-thousand)	cost
Mg-2Zn-Mn-(0.2-0.6)Ce	High plasticity medium strength	2.3-3.2	5% higher than AZ31
Mg-0.3Zr-2Zn	Medium strength and ductility	2.5-3.5	15% higher than AZ31
Mg-1Al-1Sn	Better strength and ductility	2.1-2.9	Equal to AZ31

Magnesium alloys development

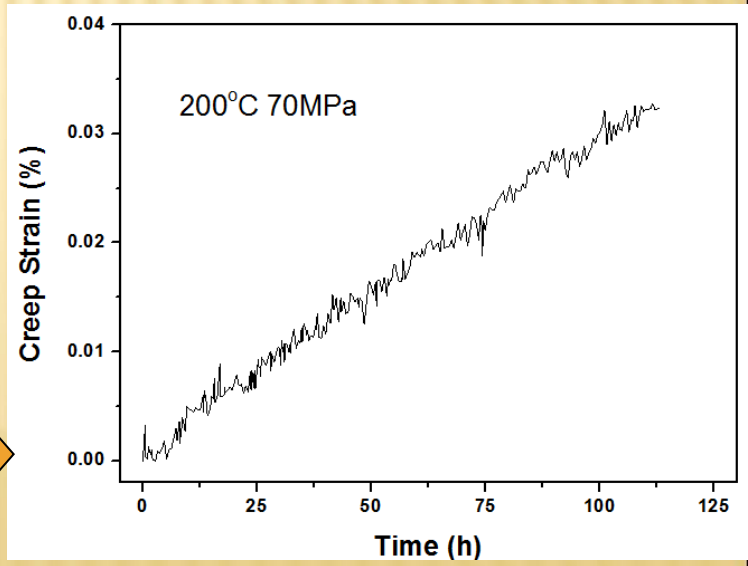
■ Creep and heat resistant cast magnesium alloy

- ✓ **Developed GW83 alloy**
- ✓ **Mechanical properties after die casting and heat treatment: σ_b 310MPa, $\sigma_{0.2}$ 230MPa, δ 9%.**
- ✓ **200°C high temperature mechanical properties: σ_b 280MPa, $\sigma_{0.2}$ 225MPa, δ 20.5%.**
- ✓ **Creep properties: 200 °C at 70MPa, the total creep of 100 hours is about 0.0036%. It is showing good creep resistance.**

Test Results

Number	thickness	measure temperature	Measuring stress	measure time	Creep strain
	mm	℃	MPa	h	%
1	1.96×5.84	200	70	100	0.043
2	1.92×5.86	200	70	100	0.031

Creep curve of peak aged GW83 alloy



Magnesium alloys development

■ High strength wrought magnesium alloy

- ◆ High-strength wrought magnesium alloy EW75M with density of 1.92g/cm^3
- ◆ RT mechanical properties after a invented whole set treatment technology:

  $\sigma_b \geq 470$ MPa, $\sigma_{0.2} \geq 390$ MPa, $\delta \geq 7\%$.

Multi direction forging+ direct extrusion

Magnesium alloys development

New die-cast magnesium alloy

- Three types of die-casting magnesium alloys, Mg-Al-Sn, Mg-Sm-Zn and Mg-Nd-Zn alloys, were developed.
- The effects of alloying elements on microstructure and properties were studied.
- The composition range, casting process parameters and heat treatment process parameters were optimized for the alloys

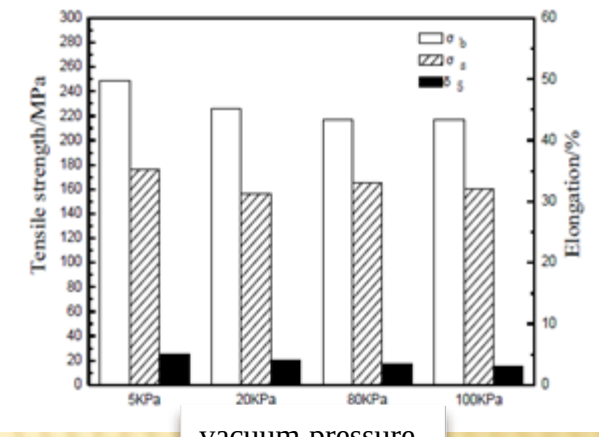
The composition of AT72 alloy is lower than that of AZ91, but its strength is similar to that of AZ91., The plasticity is improved by nearly 2 times, showing excellent comprehensive performance.

Die casting alloy	Yield Strength(MPa)	tensile strength(MPa)	Elongation(%)
Mg-9Al-6Sn	**154**	**230**	**3.4**
Mg-7Al-2Sn	**131**	**227**	**8.5**
AZ91	130	230	3
AM60	115	205	6
AM50	105	207	6
AS41	150	220	4
AE42	110	244	12

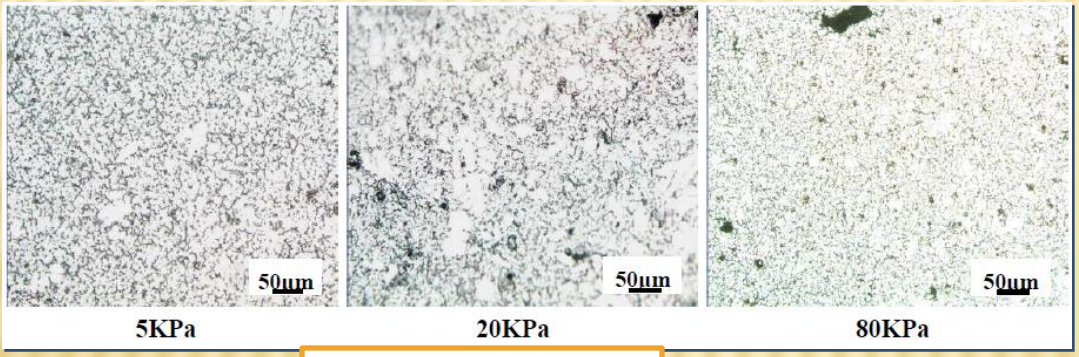
Fabrication Technologies of Magnesium alloys

High Vacuum die casting technology

- High vacuum die casting system was designed.
- The vacuum pressure less than 5 kPa can be achieved within 1.5 seconds under actual casting conditions.
- The mechanical properties is increased and the porosity is decreased

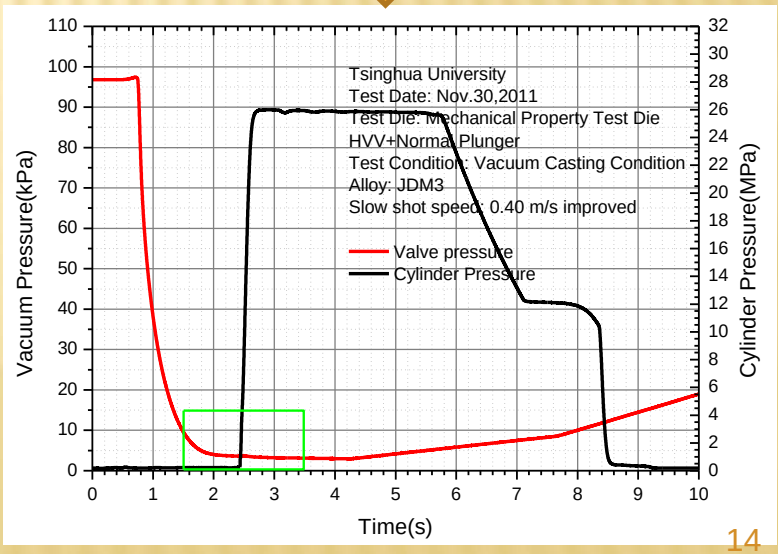


vacuum pressure



Porosity distribution

Vacuum valve pressure curve under actual vacuum die casting conditions

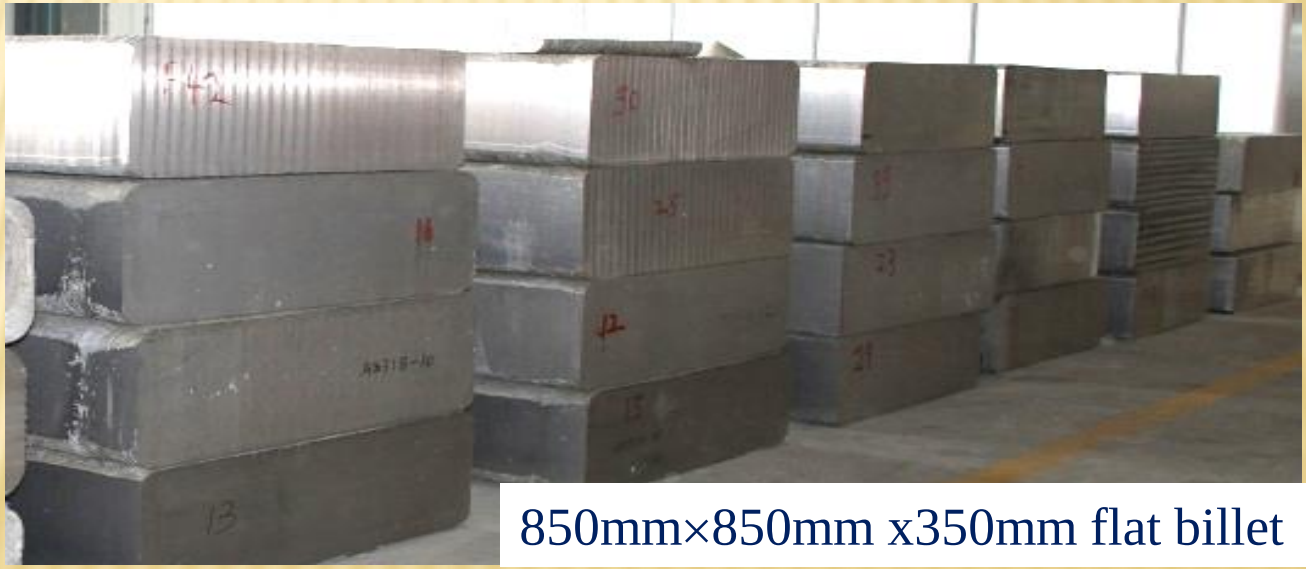


Fabrication Technologies of Magnesium alloys

■ Large size billet semi-continuous casting technology

- ◆ Large size flate billet was fabricated by semi-continuous casting technology.
- ◆ The semi-continuous casting process was optimizedin based on the analysis of flow and temperature field.
- ◆ The large size of 850mm × 850mm ×350mm flat billet of AZ31B magnesium alloy was successfully fabricated.

AZ31B magnesium alloy



850mm×850mm x350mm flat billet

Fabrication Technologies of Magnesium alloys

Wide sheet rolling technology

- Maximum width of 1600mm, a thickness range of 8mm-100mm medium plate
- Maximum width of 1500 mm and a minimum thickness of 1.0mm.
- The maximum coil weight is 1000kg.
- Mechanical properties of AZ31B sheet: σ_b = 282MPa, δ = 20.5%.

A magnesium alloy wide sheet rolling production line, with an annual production capacity of 2,000 tons.

Wide-width plate heavy reduction

Shanxi Wenxi silver light magnesium industry (Group) Co., Ltd

Fabrication Technologies of Magnesium alloys

■ Magnesium alloy sheet strip casting and rolling technology

- Developed a Low-cost,high-efficiency cast rolling technology
- Have the ability to supply the production of cast rolling sheet with width of 800mm and thickness of 2.5-8mm, sheet coils with thickness of less than 4mm and finishing rolling sheet coils with thickness of 0.3-2.5mm.
- Mechanical properties of typical AZ31B magnesium alloy: σ_b 250MPa, δ 25%, yield to strength ratio $\leq$ 0.4.

Production line with an annual production capacity of 1,000 tons of cast rolling sheet

Fabrication Technologies of Magnesium alloys

■ Extrusion-rolling technology for Mg alloy strip

- The thickness of Mg alloy strip is 0.6mm, width of 500mm.
- Single roll weight is 300kg
- Mechanical properties: σ_b=356MPa, δ=21%, sheet anisotropy factor r =1.07

Built a strip production line with the annual capacity of more than 1,000 tons

Magnesium strip rolling line

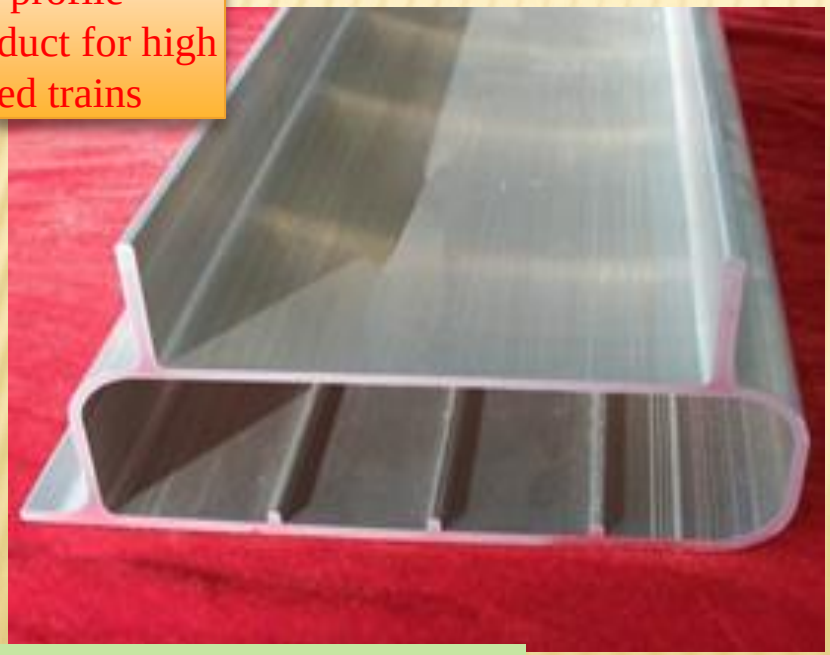
Magnesium strip roll

Fabrication Technologies of Magnesium alloys

Wide-width thin-walled hollow Mg profile technology

- A Mg profile product for high speed trains was successfully fabricated.
- The profile with the circumcircle diameter of 504 mm, the wall thickness of 1.8-3.5 mm and length of 15m and more;
- the tensile strength of the profile is 258 MPa and the elongation is 11%.

Mg profile product for high speed trains



4500 tons extrusion production line

Fabrication Technologies of Magnesium alloys

☐ Wide-width thin-walled hollow Mg profile straightening technology

- Combined using medium-temperature tension straightening technology and pressure and torsion straightening technology.
- Built a digital control special device for magnesium alloy profiles.
- The bending of the product is controlled less then 1.5mm/m, and minimum value is less then 0.5mm/m.
- It was sucessfully used in Boeing guide rail straightening.

Boeing guide rail

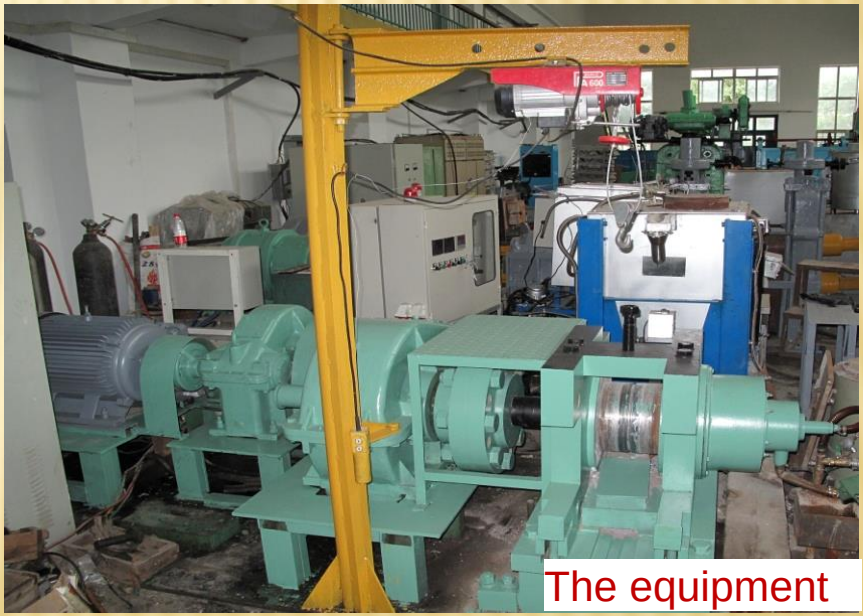
Straightening production line

Fabrication Technologies of Magnesium alloys

Continuous high-speed casting and extrusion technology

- Developed a continuous high-speed casing and extrusion technology for Mg alloys.
- For rods with a diameter of Φ8-20mm, the speed is up to 30m/min;
- For wires with a diameter of 2-4mm, the speed is up to 40m/min.

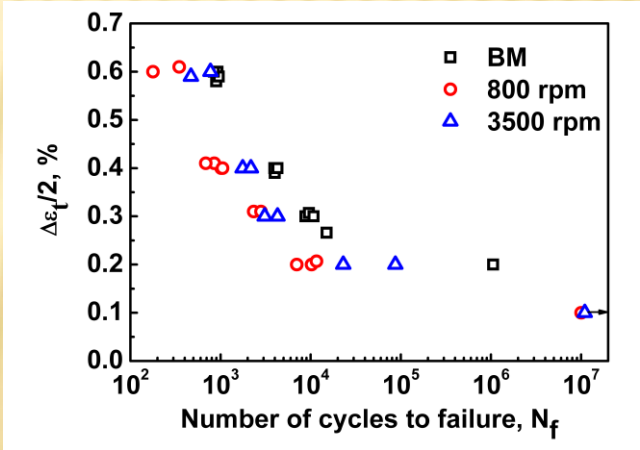
Wire production


The equipment

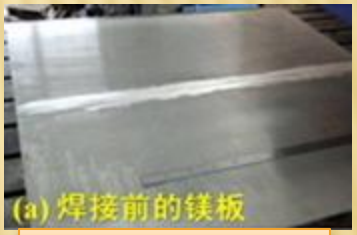
Fabrication Technologies of Magnesium alloys

Magnesium alloy friction stir welding technology

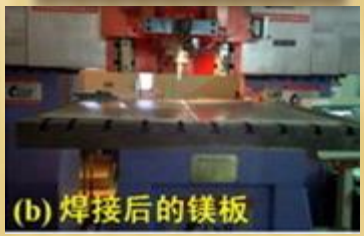
- Friction stir welding (FSW) technology was developed for the similar magnesium alloys and dissimilar magnesium alloys with different welding speeds and different plate thicknesses.
- The fatigue performance of AZ31 FSW joint at high speeds was found to be better than that at low speeds
- Two 1000 mm × 500 mm × 5 mm magnesium alloy sheets were successfully welded by FSW, and the maxium deformation is less than 3mm/m^2



AZ31 FSW joint fatigue performance



Sheet before weld

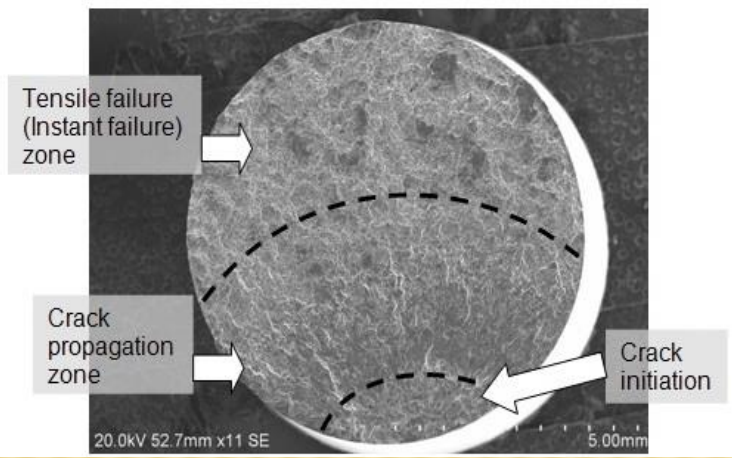


Sheet after weld

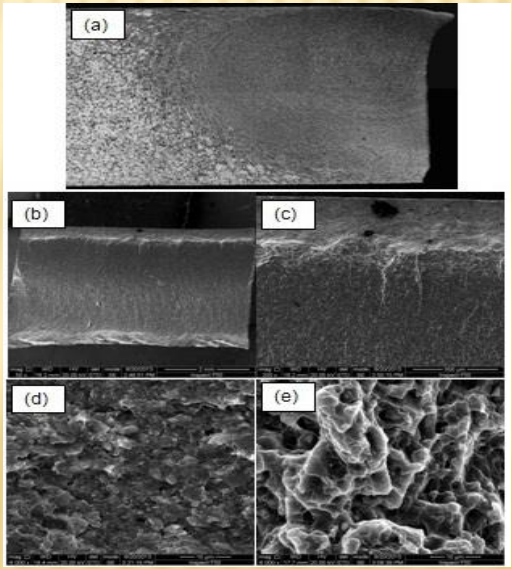
Evaluation Methods of Magnesium

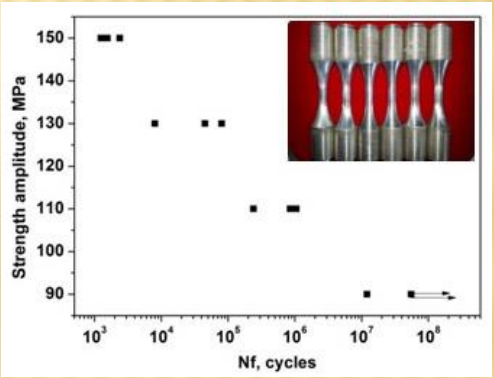
Durability evaluation

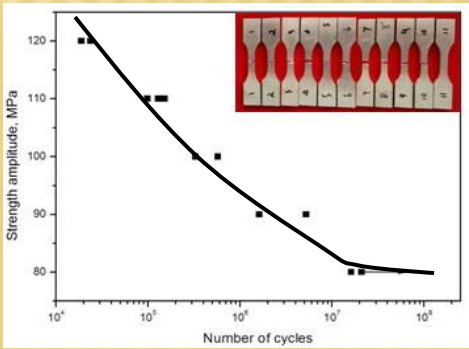
- ✓ The uniaxial fatigue life of three types of welded joints (FSSW, TIG, FSW) of four alloys (AZ31, AZ91, AM60, and ZACM) was evaluated.
- ✓ The fatigue life of ZACM alloy FSW joint exceed 1×10^7 cycle when the stress amplitude is 80MPa.
- ✓ The fatigue crack originates from the subsurface of the specimen and expands along the weld zone.



ZACM casting alloy





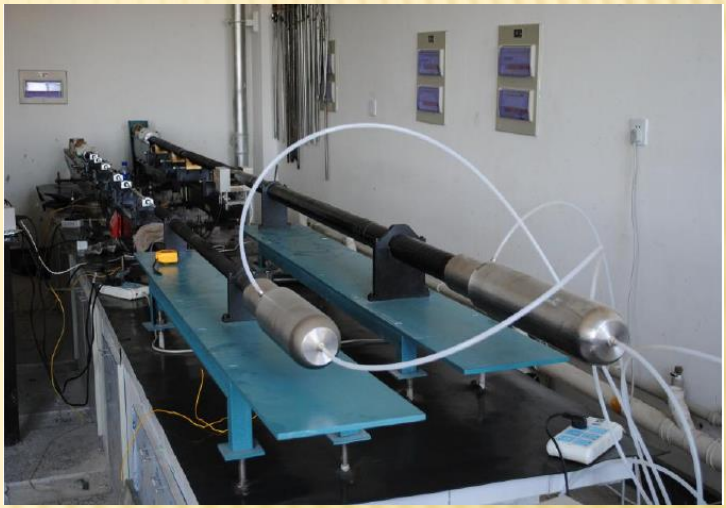


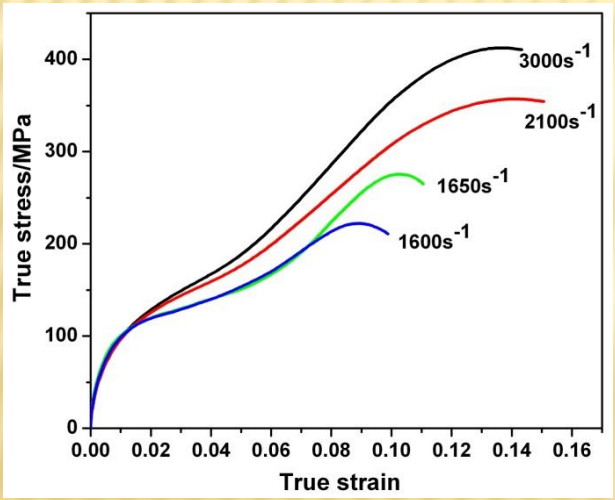
Evaluation Methods of Magnesium

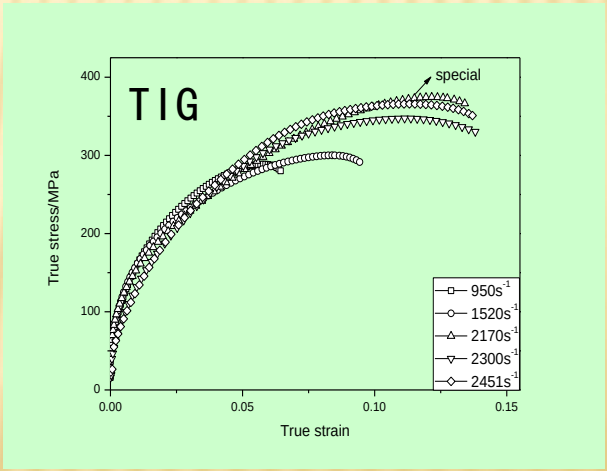
Crashworthiness evaluation

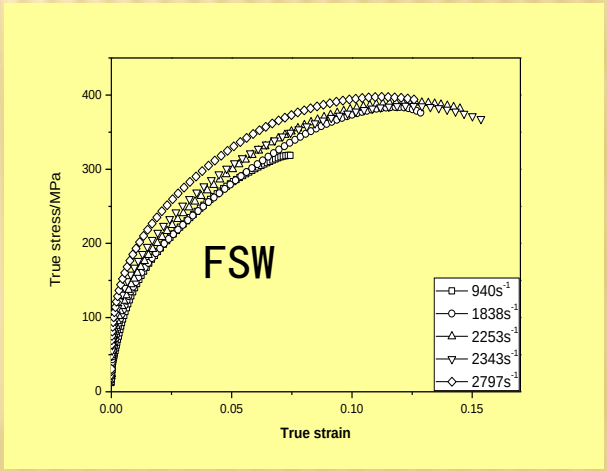
Split Hopkinson Pressure Bar(SHPB) was used to evaluate the crashworthiness of Mg alloys.

Tested materials: vacuum die-casting AM60B; die-cast AT72, as-rolled AZ31 and extruded MgGdY alloy. The joint of AZ31 alloy was also evaluated after FSW.









Rolled AZ31 alloy

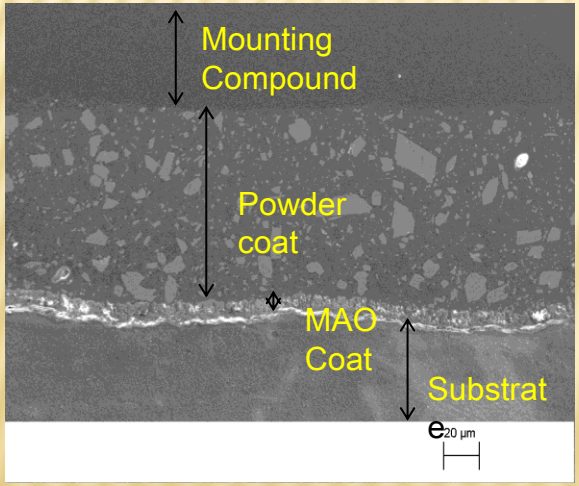
Evaluation Methods of Magnesium

Corrosion Protection Evaluation

Institute of Metal Research, Chinese Academy of Sciences

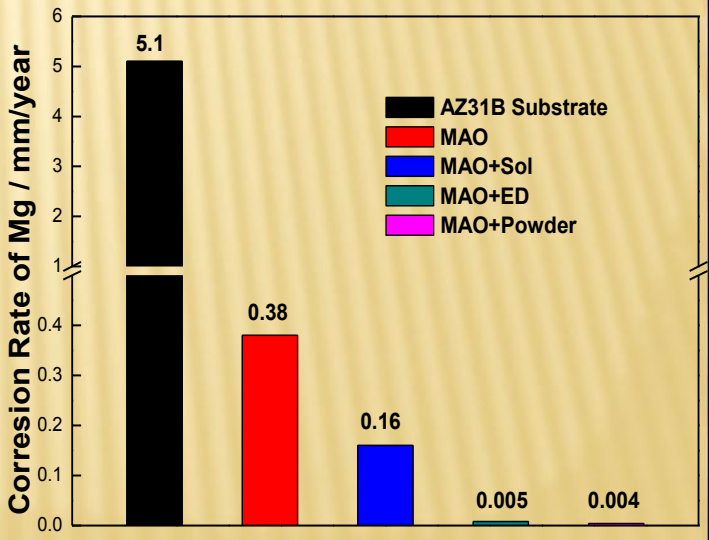
Xi'an University of Technology

- MAO(micro-arc oxidation) + electrophoretic coating,
- MAO + electrostatic spray coating
- MAO + inorganic sealing
- Self-sealing MAO coating
- MAO nano-self-assembled composite coating



MAO+ electrostatic spraying Coating surface and surface morphology

MAO+ electrostatic spraying wheel

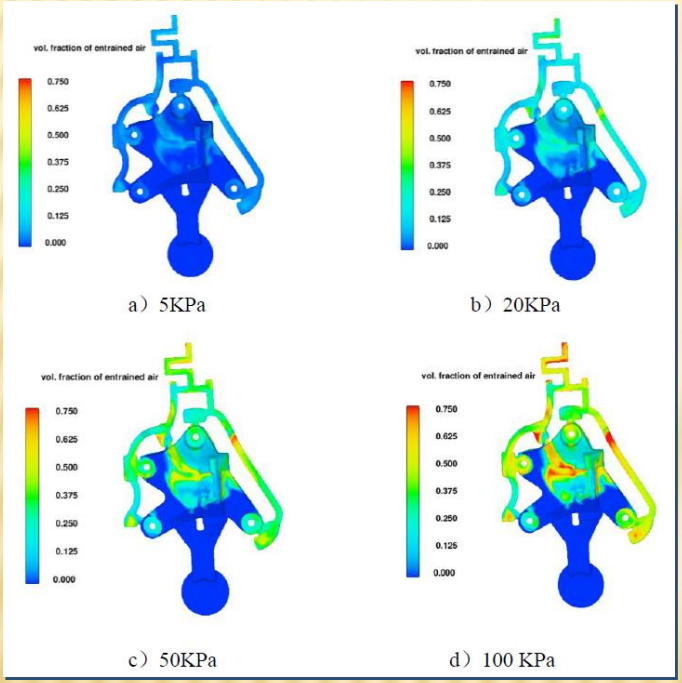


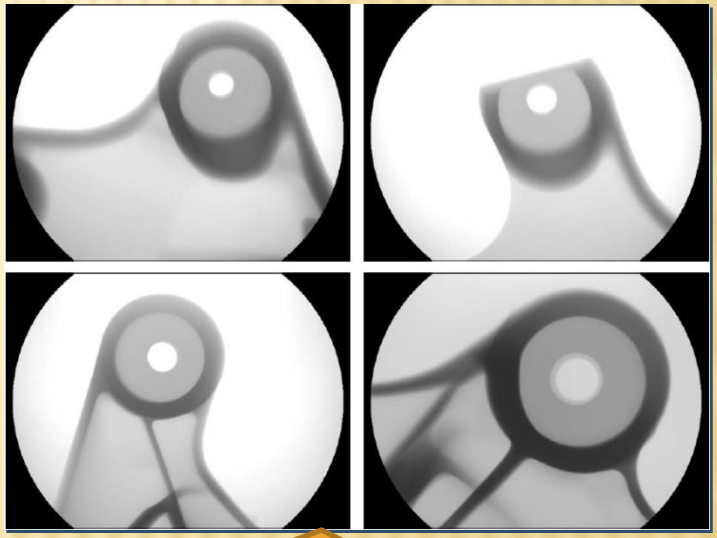
Average corrosion rate of different treated magnesium alloys

Development of Typical Magnesium components

☐ Steering gear Housing

Cadillac CTS engine bracket designed with CAE and manufactured with high vacuum die-casting technology. When the vacuum is 5KPa, the porosity is as low as 0.05%.





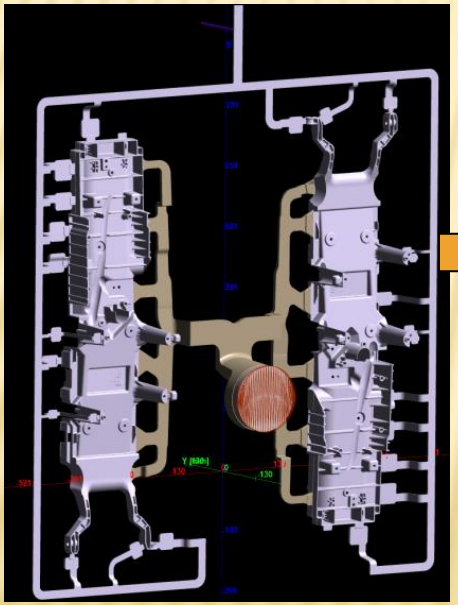
a）5KPa； b）20KPa；c）50KPa； d）100KPa

X-Ray detection

Development of Typical Magnesium components

☐ Volvo Central console bracket

- **Material: AZ91**
- **Design: CAE**
- **Technology: Vacuum die-casting. The weight of single-mode casting is 5.9 kg, the projected area of parts is about 0.4m^2, the parts porosity is less than 1.5%.**



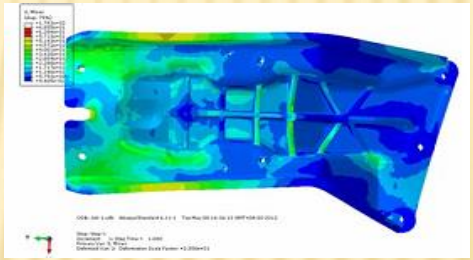
Simulation

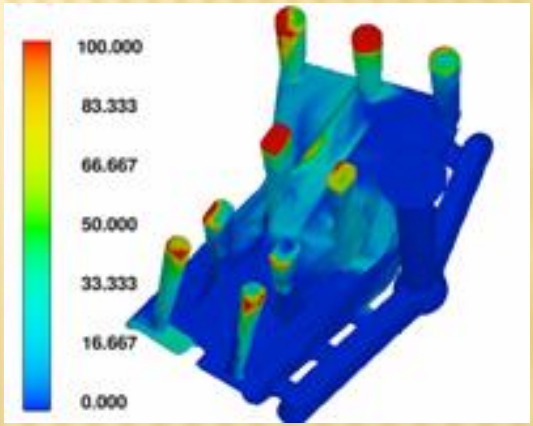
Casting: One mold two pieces

Development of Typical Magnesium components

☐ Steering column bracket (ROEWE 750)

- Material: AZ91
- Design: CAE, Topological optimization technology. a reinforced rib structure was designed to replace the think well structure where it bear weak stress
- Technology: Sand casting: pouring temperature 700℃, sand baking temperature: 200℃; graphite coating, coating thickness 0.5 mm.

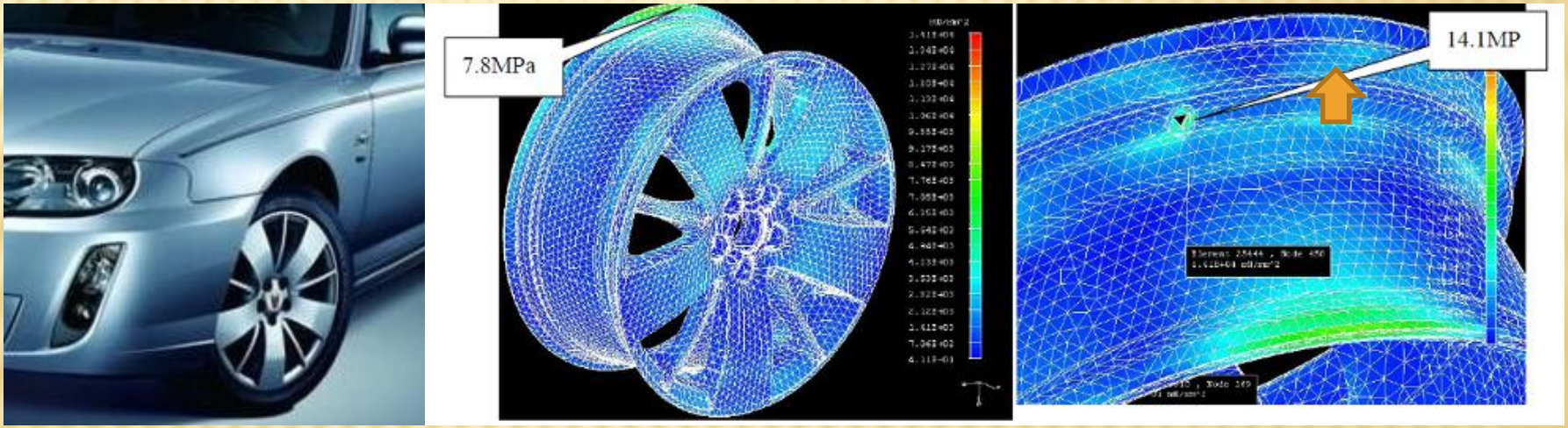




Development of Typical Magnesium components

☐ Magnesium wheel(ROEWE 750)

- Material: ZM203, JDM-1 alloy two materials
- Design: CAE analysis;
- Technology: low pressure casting, gravity casting.



Wheel radial fatigue test stress map

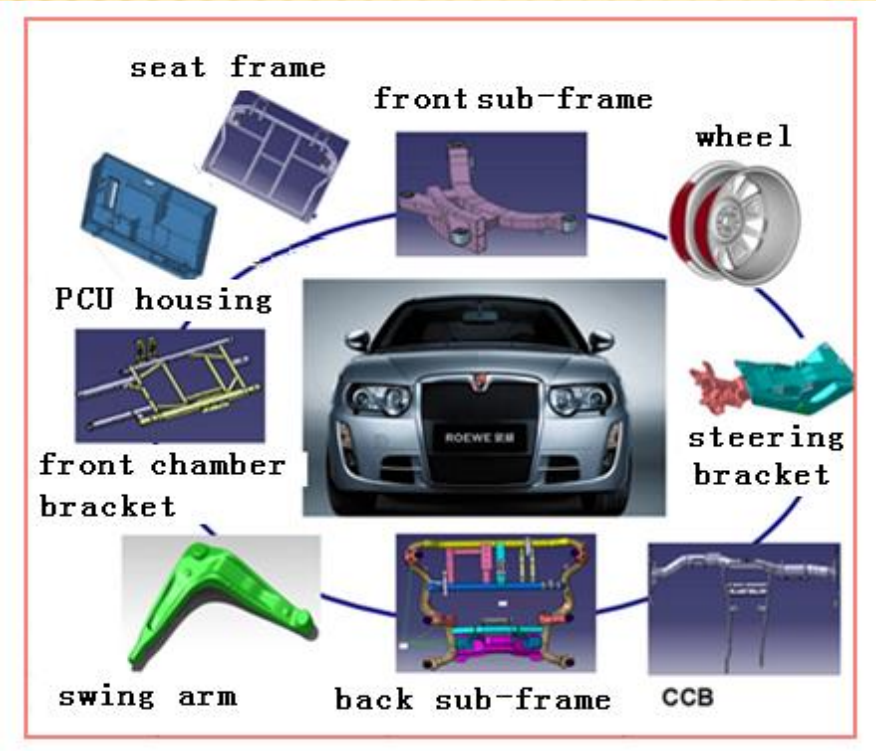
Integrated Application of Magnesium Components

Shanghai Motor Co., Ltd

ROEWE 750 PLUG-IN Fuel-cell vehicle

Synchronized with ROEWE 750PLUG-IN fuel cell sedan, 10 kinds of typical magnesium alloy components were developed. The total weight is more than 100Kg; sampling performance of typical parts is: σ_b=350MPa, δ=20%.

Magnesium alloy is 100Kg
Among them, wrought magnesium alloyis 35.727Kg



PLUG-IN fuel cell sedan

Integrated Application of Magnesium Components

Karting racing car

13 kinds of typical magnesium alloy parts with the total weight of 8.73Kg were developed for K-JSA, K-JSB and K-JSC karting racing cars. The light weight ratio is 6.8%. The racing cars passed the collision and road test.

Collision test

K-JSC Karting Racing car on the track

Development of Mg electric bus boy

- development of high performance profile

Melting

Casting

Heat treatment

Extrusion

ZTM Mg alloy profiles

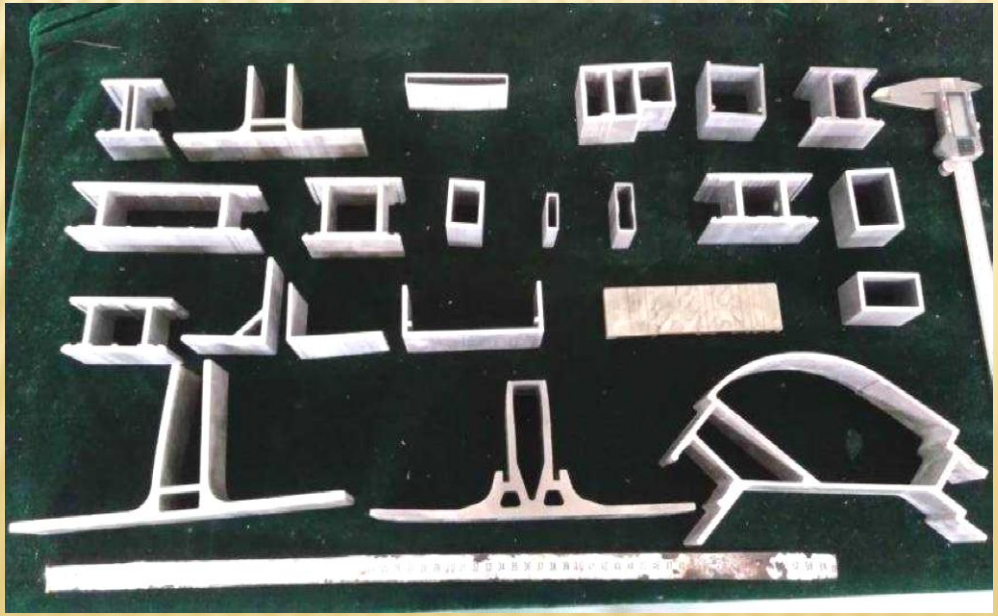
Development of Mg electric bus boy

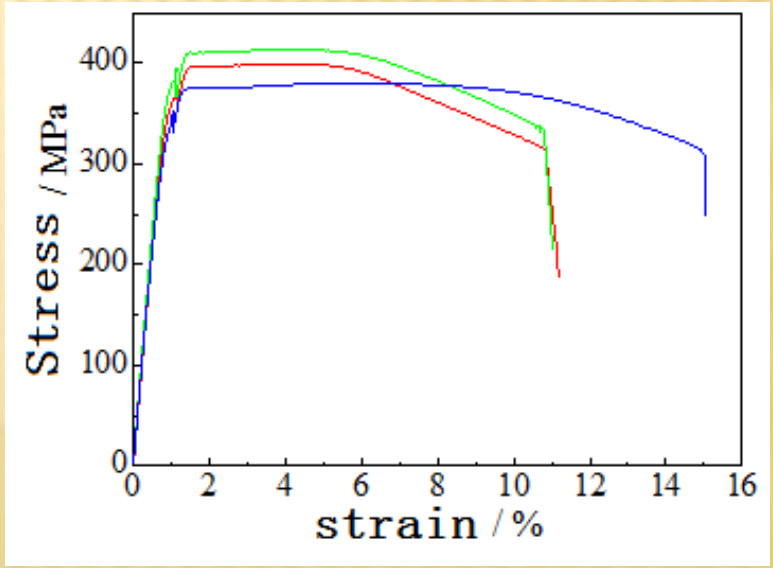
development of high performance profile

- A rapid extrusion technology was developed.
- This technology reduce the energy consumption of the equipment and increase the life of the extrusion cylinder significantly.
- A total of 23 kinds of magnesium alloy profiles were prepared by this technology, and the extruded product rate is ≥90%.
- After the surface treatment of the profile paint, the neutral salt spray corrosion test reached 9 grades over 800h, and the coating adhesion reached 0 grade.

Mechanical Properties

- UST＞350MPa
- YS＞280MPa
- δ＞10%。

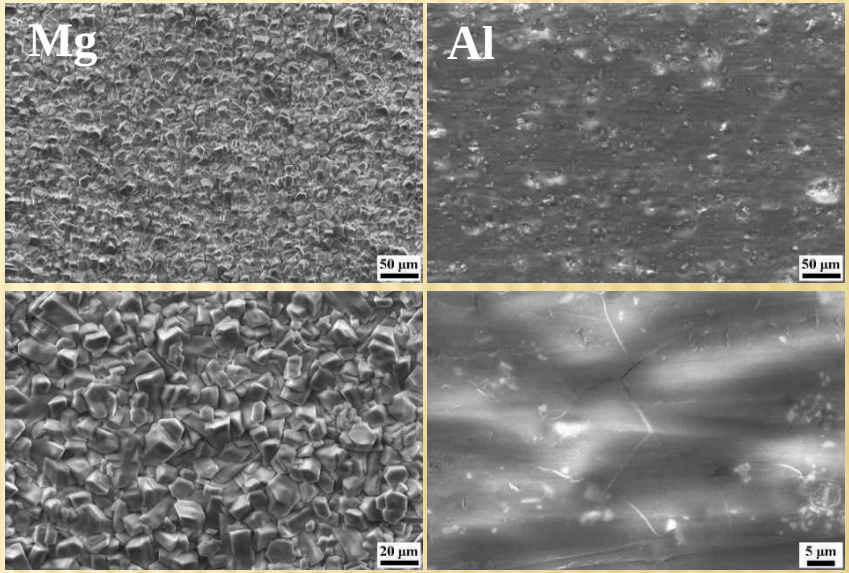




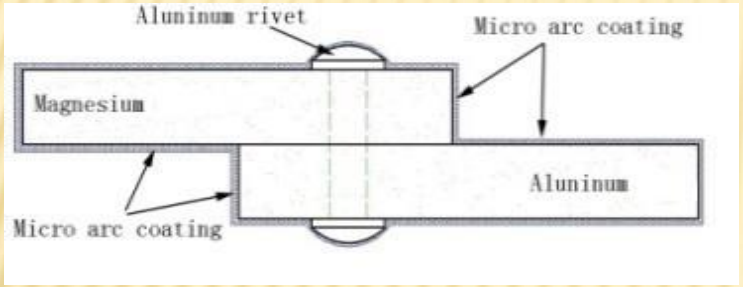
Development of Mg electric bus boy

- development of high performance profile

Developed a fluorine and chrome free phosphating technology, and it was successfully applied in the Riveting between Mg alloy and 6082 Al.

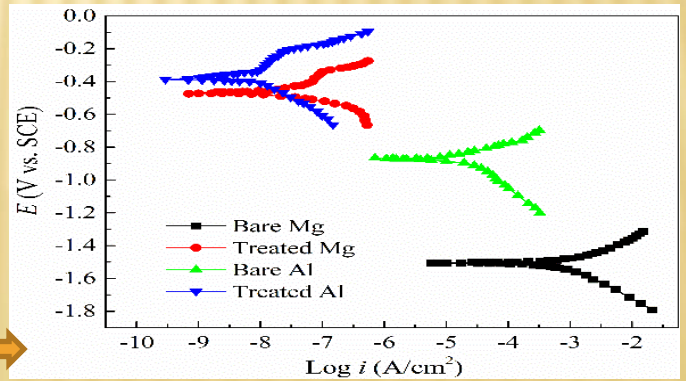


MAO of Mg-Al joint



Riveting between Mg alloy and 6082 Al profile

polarization curve

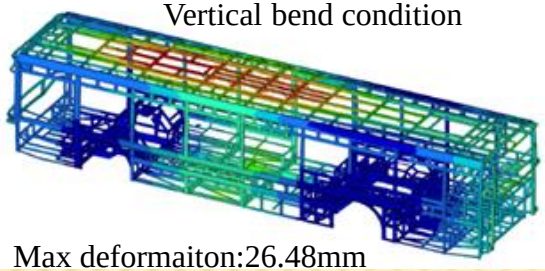


Development of Mg electric bus boy

☐ Development of Mg Bus body

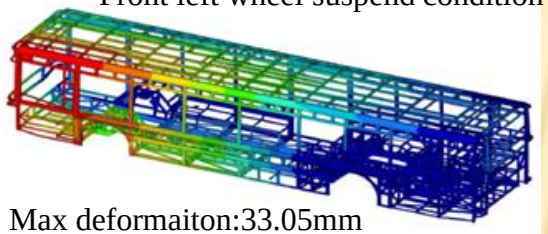
Body stiffness analysis (CAE)

Vertical bend condition



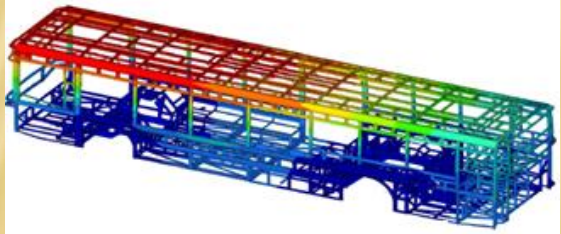
Max deformaiton:26.48mm

Front left wheel suspend condition



Max deformaiton:33.05mm

Right sharp turn condition



Max deformaiton:28.05mm

- Low temperature fast extrusion technique for Mg alloy profile
- High performance Mg alloy profile
- Mg-Al joining technique
- Surface protection technique for Mg profile.

Magnesium bus body

Application of Mg alloy in the bus body is 226Kg. Compare with the steel and aluminum body, the light weight is 780Kg and 110Kg, respectively. And the light weight ratio is 70% and 30%, respectively.

Magnesium bus demo

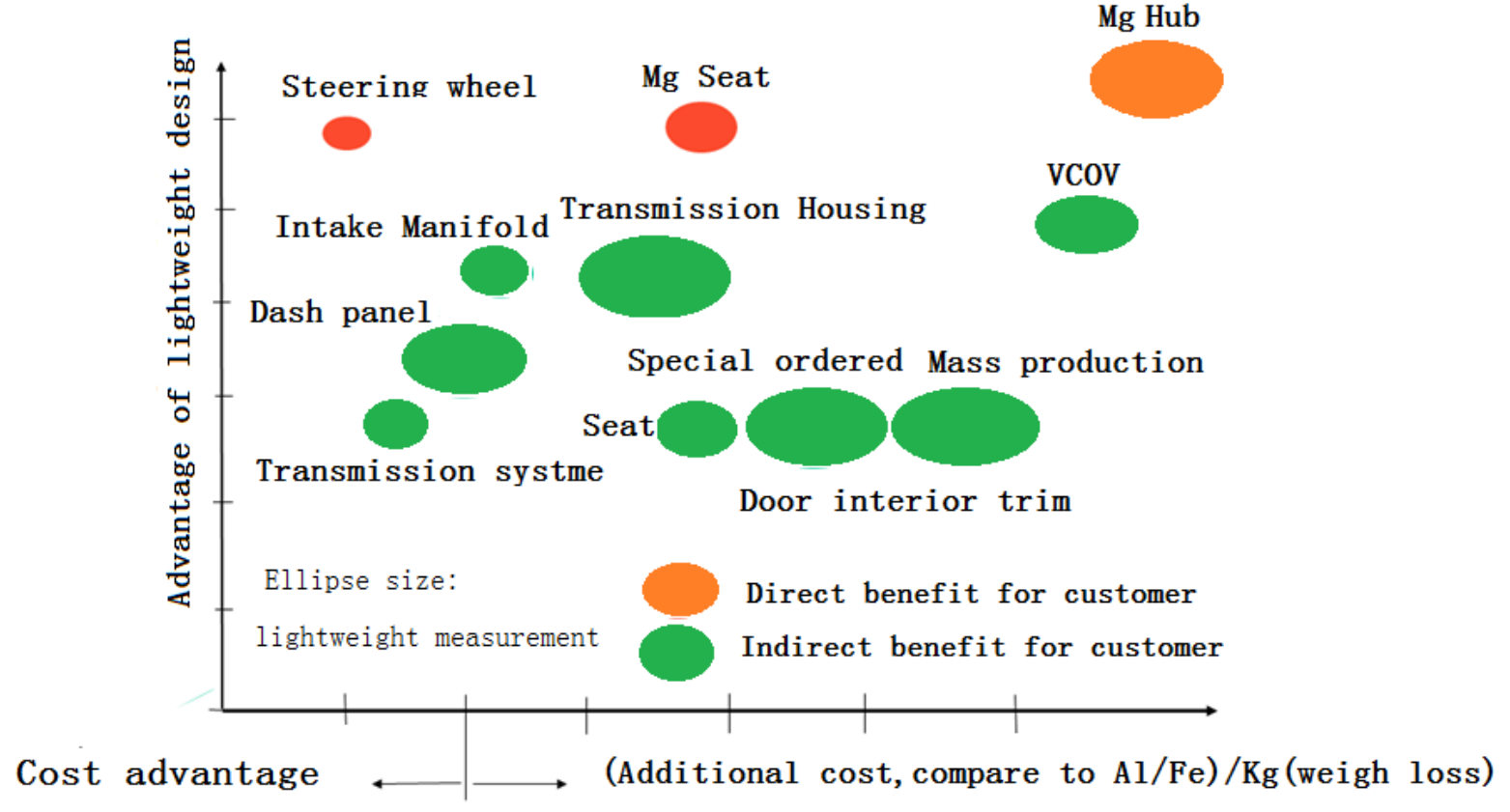
Challenges Faced with the Application of Mg

Take the advantages of materials and technology

Most experts thought that the fundamental way to solve the problems of environment protection and energy shortage is to develop the electrical vehicle. However, the weight increased by battery is an inevitable problem faced with EV. Then the questions is: how can we take the advantage of lightweight given by light metal, such as Mg, Al, Ti, ect., but avoid the drawback of weight increasing by battery?.

Challenges Faced with the Application of Mg

Let the proper materials play its own roles in proper filed



Strategies and methods to increase Mg application in automobile (Volkswagen Development Center)


Thank
you