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China's national science and technology program in research and application of magnesium alloys

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- 1 Development status of Mg Alloys in China
- 2 National Key Research and Development Plan in Mg Alloys
- 3 National Natural Science Foundation of China in Mg Alloys
- 4 Application Forecast of Mg Alloy Products
- 5 Conclusion and Outlook


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Great strategic significance of Mg alloys in China

- ◆ Mg alloy, as one of the **most lightweight** materials, is important to mitigate the energy crisis, reduce pollution and improve national security, especially to improve the "Made-in-China" competitiveness.
- ◆ China's Mg ore resources are the largest in the world, with the world's **70%**. More application of Mg alloy can also alleviate the critical shortage of other mineral resources.
- ◆ Mg alloy is included in the country's long-term science and technology development program and China's 13th 5-year plan innovation of science and technology development plan.

Automotive



Lower fuel consumption and emissions

Rail vehicle



Energy-saving, speed, security

National defense



Improve national defense security



中国制造
Made in China


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Rapid development of Mg alloy in China

2001-2015

Magnesium application increased by more than ten times in China



Complete industrial chain from high-quality Mg alloys to Mg products



High performance magnesium alloys

Advanced manufacturing technology



973Plan


863Plan

Key Technology

International Cooperation

NSFC

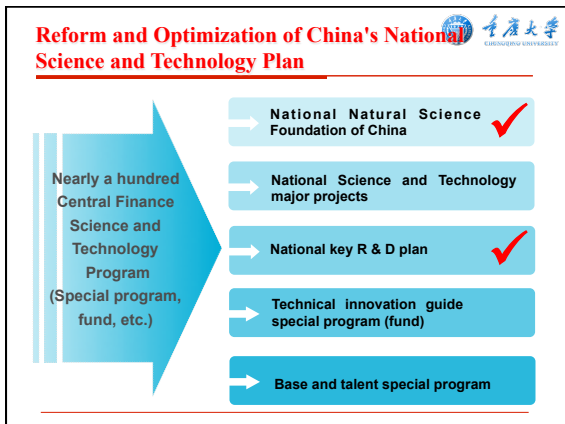



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Status and Target of Development of Mg Alloy

	Current status	Target for next 5 years
<p style="color: red; font-weight: bold;">Large-scale industrial production of cast Mg alloys</p>	<p>50% of cast Mg alloy products have been produced in China. Compared with other metals, the application of Mg is still small.</p>	<p>Large-scale production of complex, large-size, high performance castings. Application quantity of cast alloys increased by over 5 times.</p>
<p style="color: red; font-weight: bold;">Large-scale industrial production of Wrought Mg alloys</p>	<p>China has established the world's first large-scale production line of wrought Mg alloys, but the overall yield is small</p>	<p>Large-scale production of high strength, and large-size wrought products. Application quantity of wrought alloys increased by over 10 times.</p>

National Science and Technology Program



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National Key Research and Development Plan

location To break through the technical bottlenecks of the major areas of national economy

The **great social welfare research** needing for long-term evolution related to the people's livelihood.

The **great common key technologies and products, international science and technology cooperation** related to the core competitiveness of industry, overall independent innovation capability and national security,.

Reform tasks and initiatives

According to the major tasks, the National Key R&D Plan is composed of a number of **key special programs with clear objectives and clear boundaries**, and carries out innovative design, organization, and implementation of the whole chain from the basic frontier, significant common key technologies to application demonstration.



National Key Research and Development Plan

3 projects started in 2016

No.	Project Name	Leading unit	Project manager	Funding
1	Key manufacturing technologies for large-size and high-performance wrought magnesium alloy materials	Chongqing university	Fusheng Pan	¥ 34 million
2	Preparation technologies for high quality castings of high performance magnesium/aluminum alloys	Shanghai Jiao Tong University	Liming peng	¥ 34 million
3	Integrated calculation and preparation of lightweight high-strength magnesium alloys	Shanghai Jiao Tong University	Jianxin zou	¥ 20 million

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National Key Research and Development Project (I)

Key manufacturing technologies for large-size and high-performance wrought magnesium alloy materials




Leading unit: Chongqing university Project manager: Fusheng Pan

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Research background

Magnesium alloy industry in need of improvement


Status

- In the past years, the development and application of cast Mg alloys are remarkable both domestic and abroad.
- For wrought Mg alloy, the **small and medium-size rods and forgings** have begun to be applied in a **small amount**, but the production and application of large-size products are seriously lag.

Problem

- Material properties:** The wrought Mg alloys with poor plasticity are difficult to meet the application requirements.
- Processing technology:** Complex forming process, difficult production of large-scale wrought materials, backward level of technologies, poor quality, high cost.

How to realize **high-performance, large-size and low-cost** is the key to promote the large scale application of wrought Mg alloy.

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Research background

Key issues to large-scale applications of wrought Mg alloys

Severely lacking

Technical bottlenecks

Design

- High performance Mg alloys for engineering applications
- Low cost and high efficiency purification technology

Preparation

- Preparation technology of large-size cast Ingots with high purity and homogeneity

Forming


- low-cost processing technology of high-performance and large-size profiles / forgings / plate coils

Application

- Residual stress relief and surface protection of Mg alloys

Scientific issues







- The strengthening and toughening mechanism based on new strengthening phase and multi-system slip synergy.
- Migration law and mechanism of multi-attribute impurities and inclusions
- Non-uniform flow and homogeneous synergistic deformation mechanism of Mg Alloys under complex constraints.

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Research contents

Main research contents

- Design of high strength and toughness magnesium alloys and preparation of large-size cast ingot.
- Homogeneous preparation of ultra-high strength and toughness magnesium alloy profiles.
- Homogeneous preparation of ultra-high strength and toughness magnesium alloy profiles.
- Manufacturing of high precision and high formability magnesium alloy coils.
- Residual stress relief and surface protection of magnesium alloy products.

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Research objectives

Basic theory


- The new strengthening and toughening mechanism of Mg alloys;
- New design theory of strengthening phase and the purification theory of large volume and high alloying Mg alloy melts;
- deformation mechanism of ultra-high strength/large-size Mg alloy.

Common technology

- Establish 5 key preparation technologies and related equipments for high alloying and high purity ingot, high strength and toughness profiles and forgings, and high precision sheets, strips and coils;
- Develop 2 application technologies for residual stress reduction and surface protection.

Demonstration application


- Set up the integrated demonstration base for application of Mg alloys in transportation, electronic communication, aerospace, weapon equipment and other important industries and engineering fields.




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
Participating units




China's important magnesium alloy R & D base, leading unit of magnesium alloy 973 plan, national eleventh five-Year, twelfth five-year science and technology support programs, the national international cooperation programs. Possessing National Engineering research center for Magnesium Alloys, National International Joint Research Center for New Materials, National Natural Science Foundation Innovation Research Group, Ministry of Science and Technology Innovation Group, "2011 plan" National Automobile Collaborative Innovation Center. Chairman unit of magnesium alloy branch of China Materials Research Society, and editor-in-Chief of the international publication "Journal of Magnesium and Alloys".



leading domestic R & D and application of military Mg alloys. Leading unit of magnesium alloy 973 plan, key technologies R&D program, international cooperation and other related projects.




Mg alloy corrosion and protection at the international Institute of Metal Research front. Leading unit of Chinese Academy of magnesium alloy 973 and national Key R&D program Sciences



The world's largest deep processing enterprise of wrought magnesium alloys, leading unit of national key technology R&D program.



Strong experience in R & D of new high-performance magnesium alloys, Leading unit of magnesium alloy 973 project.

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Participating units

Participating units	Advantages / Characteristics
Central South University, Harbin Institute of Technology	Leading Mg alloy thermodynamics database. Specializing in ultra-high strength magnesium alloy R & D and application and aerospace research.
Zhengzhou University, Jilin University, Beihang University	Specializing in the original magnesium purification, magnesium product design and forming a significant achievement.
Northeastern University, North Central University	Mg alloy ingot, forging and corrosion and other aspects of the strength of the leading domestic, deformation of magnesium alloy sheet
University of Science and Technology Beijing	five-Year science and technology support program, defense 973 lead unit.
Longkou Conglin Aluminum Co., Ltd. Western Titanium Technologies Co., Ltd.	With 12000T extrusion system and 2800mm wide rolling mill, with the leading domestic and international advanced magnesium alloy wide plate profile production line.
China Nonferrous Metals Processing Co. Ltd., Northeast Light Alloy Co., Ltd. BacoSteel Group Co., Ltd.	Domestic magnesium alloy equipment and large-size ingots of the advantages of units, large rail transit profiles processing technology leading domestic.
Chongqing Changan Automobile Co., Ltd. Shanghai Aerospace Equipment Manufacturing General Factory. China Academy of Machinery Science & Technology	Own brand of automotive production in China first, magnesium alloy in the automotive application of outstanding results. China's satellite and rocket overall development unit, magnesium alloy in the application of spacecraft has a wealth of experience.

Project participating units are well-known in Mg alloy R & D and production at domestic and abroad.


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National Key Research and Development Project (II)

Preparation technologies for high quality castings of high performance magnesium/aluminum alloys




Lead unit: Shanghai Jiao Tong University Project manager: Liming Peng

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Research background


Status

- Vehicle lightweight is an inevitable choice to solve the global problems such as energy shortage and environmental pollution. The main technical way to realize the lightweight of automobile is to replace steel with aluminum and magnesium. Die casting has become the first choice to meet the needs of high performance lightweight magnesium/aluminum alloy castings.

Problem

- Three key technologies on high performance magnesium / aluminum alloys need to be developed: the materials for high quality die casting, integrated design and application, and forming technology and equipment.


The project will carry out the innovation of key technologies for integrated product design, high compactness die casting process and equipment, and application verification, to promote the development of China's magnesium/aluminum alloys -high quality manufacturing-automobile lightweight in whole industry chain.

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Research contents

Main research contents

- Research on the basic issues of the design and preparation of high performance magnesium / aluminum alloys for automobile structural application.
- Development of key technologies and demonstration parts for large, complex and thin wall magnesium alloy die castings.
- Development of key technologies and demonstration parts for semi-solid die casting and liquid die forging of high performance aluminum alloys.
- Development of low cost and high efficiency pressure casting equipment suitable for large and thin wall magnesium alloy die casting and semi-solid aluminum alloy die casting.
- Integration, evaluation and demonstration verification of magnesium/aluminum alloy parts, accomplish bench testing and vehicle loading evaluation on magnesium/aluminum alloy demonstration parts, and form mass production capacity of high quality magnesium/aluminum alloy castings.

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Research objectives

- Reveal the formation and affecting mechanisms of first solidification precipitation and solidification defects of magnesium/aluminum alloy.
- Develop more than 5 kinds of high performance die cast magnesium/aluminum alloys and semi-solid die cast aluminum alloys.
- Master magnesium alloy die cast and defect control technologies
- Master the technologies of aluminum alloy semi-solid slurry preparation, semi-solid die casting and liquid die forging.
- Develop 7 kinds of new automotive die-casting structural parts.
- Develop low-cost magnesium/aluminum alloy semi-solid die-casting equipment.
- Finish the integrated examination and verification of demonstration parts and realize industrial production capacity.

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Participating units



General Research Institute for Nonferrous Metals



Dongfeng Motor Corporation



Shanghai Light Alloy Net Forming National Engineering Research Center Co. Ltd.



Tsinghua University



Beijing University of Technology



Zhengzhou University



Shanghai Jiao Tong University



Nanjing University of Aeronautics & Astronautics



Hefei University of Technology



银宝山新
Shenzhen Yinbaoshan New Die-casting Science and Technology Co. Ltd.




上海志比合金材料有限公司
Shanghai Zhibi Alloy Science and Technology Co., Ltd.



Shanghai Yida Machinery Co. Ltd.



凤翔爱尔合金压铸有限公司
Fengsang Aircel Light Alloy Net Forming Co. Ltd.

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National Key Research and Development Project (III)

Integrated calculation and preparation of lightweight high-strength magnesium alloys




Leading unit: Shanghai Jiao Tong University Project manager: Jianxin Zou

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Research background

Material genome: New model for material development

Status: Traditional materials research and development mode is suffering from long cycle and low efficiency, and can not meet the requirements of rapid development of China's material industry. Material design, preparation and characterization based on "Materials Genome" are becoming the dominant mode of materials R&D.

Connotation: Combination of high-throughput calculations, high-throughput experiments and material fundamental databases.

Target: Achieve double halves of R & D costs and cycle through large-scale efficient screening and microstructure-performance prediction.

➢ Using material genomics to accelerate the development of new materials has important strategic significance for the promotion of China's independent research and development of materials.

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Research background


Research and development status of Mg alloys

Advantage: low density, high specific strength, high rigidity, rich resources.

Disadvantage: low strength, poor plasticity, lack of toughness design methods and basic data, slow development of new high-performance magnesium alloys.




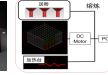

Urgent needs: Use Mg alloy as the carrier to explore the genome development mode of metallic structural materials, to achieve a breakthrough in mechanical properties of Mg alloys and reduce R&D costs and cycles.

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Research contents

Main research contents

- Research on key feature structure and alloy design criteria of magnesium alloys.
- Calculation of concurrent high-throughput and construction of basic parameter database.
- High throughput preparation of bulk samples and rapid characterization of microstructure and properties.
- Magnesium alloy microstructure simulation and performance prediction.
- Development and demonstration application of high performance magnesium alloy.









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Research objectives

- ◆ Based on the model of strengthening and toughening of magnesium alloys and design criteria, this project will get through the data transfer channel of cross-scale calculation. Through integrated calculation of composition design – process – microstructure/defect – performance, this project will realizing composition screening of magnesium alloys.
- ◆ The method of powder injection molding and cold spraying will be developed to prepare magnesium alloy block samples and establish a sample database. To optimize the database and magnesium alloy composition using quickly characterization technology of microstructure and performance.





To achieve high-performance magnesium alloy R & D cycle and cost reduction reduced by 20%

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Participating units



Zhejiang University


Northeastern University


Dalian University of Technology


Northwestern Polytechnical University



Central South University



Chongqing University


Tsinghua University


University of Science & Technology Beijing



Shanghai Jiao Tong University


Nanchang University


Tianjin University


 Shanghai Jiao Tong University



Shanghai Aerospace Precision Machinery Research Institute


Chongqing Changan Automobile Co., Ltd.


Shanghai Fangke Automobile Parts Co., Ltd.


Materials Research Institute of Chinese Academy of Engineering Physics


Advanced Materials Institute of Shandong Academy of Sciences


Bouton Research Institute of Rare Earths

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National Natural Science Foundation of China

location




Enhance the source innovation capacity

Being focused on **basic research**, **scientific frontier** and interdisciplinary and cultivating outstanding scientific research personnel and team.


Reform tasks and initiatives

To further improve the management, increase funding and transport innovative knowledge and talent team to the national key research fields. **To join into the national science and technology management platform**, strengthen coordination with other science and technology programs and effective docking, and avoid repetition financial support.

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National Natural Science Foundation of China


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Key projects of NSFC



4 key projects started in 2016-2017

No.	Project Name	Leading unit	manager	Funding
1	Mechanism of weakening basal texture of wrought magnesium alloys through controlling composition and process	Chongqing university	Fusheng Pan	¥ 2.95 million
2	Grain refinement and plasticity control of magnesium alloys	Shanghai Jiao Tong University	Xiaoqin Zeng	¥ 2.84 million
3	Fundamental research on alloying design and asymmetrical rolling deformation of low-cost, high-strength and ductile magnesium alloy sheets	Northeastern University	Jianxin zou	¥ 2.88million
4	Key scientific issues of magnesium alloy corrosion and protection	Institute of metal research, CAS	Fuhui Wang	¥ 2.9million


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Mechanism of weakening basal texture of wrought Mg alloys through controlling composition and process

Research Background

◆ Wrought magnesium alloys have a HCP structure a big c/a ratio and a low stack fault energy. Their current process is the general simple rolling or extrusion. The strong basal texture and twinning are easily formed. Meanwhile the mechanism is not clear and need to be deeply studied and hence the development and application of wrought magnesium alloys with a weak texture is restrained.

➤ How to weaken basal texture has become a key problem in the development and application of wrought Mg alloys and a hot issue in the field of magnesium alloys all over the world.

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Mechanism of weakening basal texture of wrought Mg alloys through controlling composition and process

Main research contents

- ◆ investigate the calculation and characterization of materials parameters, and study the relationship between plastic deformation mechanism, basal texture and materials parameters.
- ◆ Investigate the intrinsic relationship among alloy **composition - materials - parameters - deformation mechanism - basal texture**.
- ◆ Study the effects of solute atom and its segregation on microstructure, **recrystallization**, and basal texture.
- ◆ uncover the stress and strain conditions to promote **the non-basal slide** and c -axis tilt, simulating and calculating the expression equation between the shear **strain** and **asymmetric strain**, and basal texture under multiple deformation models.
- ◆ Characterize the atom motion and arrangement, microstructure evolution and non-basal c -axis orientation of typical magnesium alloys during **asymmetric deformation**.

Objectives


- ◆ The formation and weakening mechanism of macro-texture will be clarified, the regulation rules of alloy composition and asymmetric deformation will be established to weaken the basal texture, and the control method of composition and process and the technology prototype will be proposed.

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Grain refinement and plasticity control of magnesium alloys

Research Background

- ◆ Enhancing the room temperature ductility of Mg alloys is very important for their wide application in industry.
- ◆ Grain refinement is a useful way for ductility enhancement.
- ◆ The influence of grain size on the mechanical properties for Mg is multi-scale problem. So far, **there is no universal theory to describe the relationship between grain size, micro-deformation mechanism, and macroscopic mechanical properties in Mg**.

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Grain refinement and plasticity control of magnesium alloys

Main research contents

- ◆ How grain size affects the competition between slip and twinning, basal slip and non-basal slip.
- ◆ How grain size affects the slip transfer at grain boundary.
- ◆ How grain size affects the stability of $\langle c+a \rangle$ dislocation.
- ◆ How the alloying affects slip and twinning.

Objectives

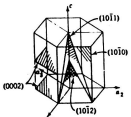
- ◆ Establish a general theory to connect grain size and ductility for various Mg alloys. The theory will be useful for new alloy development and improve processing technologies in the future

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Fundamental research on alloying design and asymmetrical rolling deformation of low-cost, high-strength and ductile magnesium alloy sheets

Research Background

- ◆ In order to expand widely industrial applications of Magnesium alloys, it becomes more and more important to develop the Mg sheet with low-cost, high strength and high elongation simultaneously.




- > Hcp structure
- > 3 basal slip system (0001) $\langle 11\bar{2}0 \rangle$
- > Twinning (10 $\bar{1}2$) $\langle 10\bar{1}1 \rangle$
- > Basal texture



Poor formability

This project is based on the recently developed non-RE high strength Mg-Ca-Sn alloy (yield strength ~409MPa) and high densities of Ca-rich nano-lamella.

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Fundamental research on alloying design and asymmetrical rolling deformation of low-cost, high-strength and ductile magnesium alloy sheets

Main research contents

- ◆ Investigate stacking fault (SF) energy and solute segregation energy around SFs for Mg-Ca based alloys to design Mg alloy systems with low SF energy.
- ◆ The alloy is then extruded and rolled in differential speed. Formation mechanism of the nano-lamellas and their effects on grain growth behaviors will be studied, to reveal the grain refinement hardening mechanism.
- ◆ Effect of solute elements on nucleation and growth of compressive twinning will be investigated to reveal mechanism of twinning induced dynamic recrystallization and also formation mechanism of RE texture.
- ◆ Combined with annealing, the static recrystallization behaviors of the as-rolled Mg-Ca based alloys, and also the mechanism of abnormal grain growth will be clarified to produce the bi-modal grain structure and improve ductility of sheets.

Objectives

- ◆ The relationships between deformation processing, microstructures and mechanical properties of Mg-Ca based alloys will be established, to provide basis of designing newly low-cost, high strength and ductile Mg alloys sheets.


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Key scientific issues of magnesium alloy corrosion and protection

Research Background

Poor corrosion resistance has always been a key issue in restricting the widespread application of magnesium alloys. At present, corrosion and protection of magnesium alloys are facing three bottlenecks.

- ◆ The research on the corrosion theory of the new magnesium alloy lags behind the design and preparation of the alloys and it is difficult to provide theoretical guidance for the development of new high strength and corrosion resistant magnesium alloy.
- ◆ How to carry out anti-corrosion treatment for magnesium alloys with different components, processing technology and pretreatment is lack of systematic research.
- ◆ Protective coating technology research on its common issues is lacking and the development of process design theory lags behind.

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Key scientific issues of magnesium alloy corrosion and protection

Main research contents

- ◆ Using Mg-Al alloy and Mg-RE-Zn alloy as the research system, the project will investigate the effects of new microstructure and new environment on the corrosion behavior of magnesium alloys, clarify the corrosion mechanism of new magnesium alloy.
- ◆ Construct the correlation between composition, process, pretreatment state and corrosion resistance of protective coatings.
- ◆ Based on the concept of Louis acidity / pH, the project will also study four new concept protective coatings including chemical conversion film, self-densified micro-arc oxidation film, conductive-corrosion resistant functional coating and ocean temperature self-repair coating.

Objectives


- ◆ The corresponding process design theory will provide scientific basis and theoretical support to solve the problem of corrosion and protection of magnesium alloys.

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Common projects of NSFC








132 projects started in 2016-2017

Type	General	Young	Region	Cooperation
Number	62	55	12	3



main research fields: microstructure and mechanical properties, plastic deformation, biomedical magnesium alloys, corrosion and protection, magnesium-based composites, and structure and function integrated magnesium alloys.

Main host units

 Chongqing University
  Shanghai Jiao Tong University
  Harbin Institute of Technology
  IMR
Institute of Metal Research of Chinese Academy of Sciences
  Northeastern University
  Central South University
  Zhengzhou University



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In the field of automobile

Cast and wrought Mg alloy products



 Shock absorbers	 Engine block	 Seat framework basin	 Battery shell
 Wheel hub	 Anti-collision beam	 Door inner panels	 Luggage compartment partitions




In the field of rail vehicles

Mg alloy profile and sheet products










 High-speed train inner decoration	 High-speed train skirt panel	 Rail vehicle pillow beam profile
 Air conditioning ventilation grille	 High-speed train seat and table	 Rail vehicle pillow beam profile



In the field of electronic information


Mg alloy sheet products (shell pieces)

 Tablet PC	 Digital camera	 Unmanned aerial vehicle
 Mobile phone	 Laptop	 Digital Camera






In the field of aerospace

Mg profiles, sheet and forging products



The expected magnesium alloy components are **aviation containers, propellant bearing chamber of carrier rocket, satellite carrying support cabin, spacecraft resource cabin, satellite battery shell pieces, satellite end box, spacecraft electronic chassis and so on.**

 Aviation container	 Satellite components	 Carrier rocket components
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In the field of national defense

Cast and wrought Mg alloy products

Missile tail, missile shell, missile cabin, tank load wheels, light artillery baseplate, military aircraft engine casing and ground wheels and other parts.

 Fighter	 Tank	 Helicopter
 Missile	 Gun sight	 Command shelter

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Conclusion and Outlook

- ◆ **National Key Research and Development Plan, National Natural Science Foundation of China and other important science and technology projects** continue to increase the investment on Mg alloy R&D and application during the 13th 5-year plan, which is an **important boost** for the development and expansion of China's Mg industry and large-scale application of products. This is beneficial to get through Mg industry chain and realize great integration innovation.
- ◆ Through the implementation of the National Science and Technology Programs during the 13th 5-year plan, it is expected to make important breakthrough in the **key manufacturing technology and development of wrought and cast products**. This will further strengthen and consolidate the basis for technology development of China's magnesium alloy products and industrial development, promote high-performance magnesium alloy products to achieve large-scale applications in **automobile, rail vehicles, aerospace, defense industry, electronic communications** and other key areas. The application quantity of China's Mg products is expected to achieve **multiple growth in the next few years**.

