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# Key R&D activities for development of new types of wrought magnesium alloys in China

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**Abstract:** Many researchers in China are actively engaged in the development of new types of wrought magnesium alloys with low cost or with high-performances and novel plastic processing technologies. The research activities are funded primarily through four government-supported programs: the Key Technologies R&D Program of China, the National Basic Research Program of China, the National High-tech R&D Program of China, and the National Natural Science Foundation of China. The key R&D activities for the development of new wrought magnesium alloys in China are reviewed, and typical properties of some new alloys are summarized. More attentions are paid to high-strength wrought magnesium alloys and high-plasticity wrought magnesium alloys. Some novel plastic processing technologies, emerging in recent years, which aim to control deformation texture and to improve plasticity and formability especially at room temperature, are also introduced.

**Key words:** wrought magnesium alloy; microstructure; properties; alloy designing; plastic deformation; research projects

## 1 Introduction

In the past years, the annual output of magnesium has increased remarkably in China, and magnesium alloys are being applied to motorcycles, automobiles, electric devices and so on. However, more extensive application has not yet commenced due to the high cost of sheets and profiles of wrought magnesium alloys and their unsatisfactory properties. Nowadays, the research and development (R&D) on high-performance wrought magnesium alloys and novel forming processes have received much more global attention than ever before, and many R&D projects have been supported by the central government and local government.

In China, the research on wrought magnesium alloys is mainly conducted in Chongqing University (CQU), Shanghai Jiao Tong University (SJU), Institute of Metal Research of Chinese Academy of Sciences (IMR), Changchun Institute of Applied Chemistry of Chinese Academy of Sciences (CIAC), Central South University (CSU), etc. Research funding primarily come from four government-supported programs, namely, the Key Technologies R&D Program, the National Basic Research Program of China, the National High-Tech R&D Program of China, and the National Natural Science Foundation of China. In the present work, the key R&D activities on wrought magnesium alloys in China, including arrangement of national research projects for wrought magnesium alloys and development of new types of wrought magnesium alloys and novel plastic processing technologies, are introduced and discussed.

## 2 R&D projects on wrought magnesium alloys in China

### 2.1 Projects under the National Key Technologies R&D Program

The Key Technologies R&D Program is the first

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national science and technology (S&T) program in China. It aims to address major S&T issues on national economic construction and social development. Initiated in 1982 and implemented through 4 Five-year Plans, the program has made remarkable contributions to the technical renovation and upgrading of traditional industries and the formation of new industries.

At the beginning of this century, Chinese government has started two rounds of (two Five-year Plans from 2000−2010) R&D projects for magnesium and its applications (shown in Table 1) under the Key Technologies R&D Program of China. With the guidance of the Ministry of Science and Technology (MOST), Chinese magnesium industry made rapid progress through these projects. A complete industrial production chain, including primary magnesium and its alloy making, die-casting, extruding, rolling, welding, surface protection was set up. The annual output of Chinese primary magnesium increased stably step by step and reached 627 300 t in 2007, about 70% of the world output. The amount of various magnesium alloy products used in automobiles, motorcycles, bicycles, and 3C electronics increased rapidly, and the application field of magnesium expanded quickly as well. It can be seen from Table 1 that most of the sub-projects under this programme are related to development and application of processing technologies of wrought magnesium alloys.

### 2.2 Projects under the National Basic Research Program

In 2007, the National Basic Research Program of magnesium alloys titled "Key Basic Problems during Preparation and Processing of High Performance Magnesium Alloys" organized by Chongqing University was approved, and the total fund is 31 million RMB Yuan. Many universities and institutes in China have joined this project. This project is closely related to great national strategic demand, and aims to solve the key technological bottleneck of preparation and processing of high-performance wrought magnesium alloys. The key scientific problems, research sub-subjects as well as general objectives can be seen in Table 2.

Some important innovative research results related to the basic problems by this project have been obtained in the past two years, including:

1) new purification flux and electromagnetic semi-continuous casting technique;

2) influence of initial grain and temperature on deformation behavior;

3) mechanism of the competition between dislocation slip and twinning;

4) grain refinement;

5) law of second phase strengthening and toughening;

6) optimized combination of strength and damping capacity.

These obtained results provide direct technological support for extrusion of the profiles with large cross section and processing technique of large-dimension sheets. Through these projects, about 130 papers have been published and 53 patents have been applied.

**Table 1** Projects on Mg and its alloys supported by the National Key Technologies R&D Program

| Project | Year | Fund/$10^6$USD | Research sub-project |
|---|---|---|---|
| Application and key technologies of Mg and its alloys | 2000−2005 | 10 | Mg metallurgical technologies and equipments<br>Mg die casting and its application in automobile industry<br>Mg extrusion and its product development<br>Mg sheet rolling and its application in 3C products<br>Mg welding and surface protection<br>Mg refining and recycling technologies and equipments<br>Processing and application of MgO products<br>Development and industrialization of Mg die casting equipment and its gas-protection system |
| Key technologies development and application of Mg and its alloys | 2006−2010 | 6 | High quality Mg alloy processing technologies<br>Advanced processing technologies of Mg sheet production<br>Low-cost processing technologies of Mg profile production<br>Complex Mg castings and integrated processing technologies<br>Welding and surface protecting technologies of Mg alloys<br>Advanced technological development for Mg electrolyzing and anhydrous $MgCl_2$ processing<br>Mg metallurgical production by silicon reduction with energy-saving and environment-protecting<br>Special deformation technologies of Mg alloy products and basic standardization system for Mg researches and industrialization |

**Table 2** National Basic Research Program for wrought magnesium alloys

| Item | Content |
|---|---|
| Sub-projects | Basic research on Mg alloy melts purification<br>Basic research on Mg alloy liquid forming<br>Research on plastic deformation mechanism and plastic processing theory<br>Strengthening-toughening mechanism and structure-property relationships<br>Basic research on the failure behavior and corrosion behavior of Mg alloys<br>Basic research on new technologies and new methods of Mg alloys |
| General objective | Establish the theory of multilevel composite purification and liquid forming<br>Develop fine-grained and homogeneous solidification forming technique prototype<br>Elucidate the microcosmic physical essence of plastic deformation of Mg alloys<br>Develop the basic theory of enhancing plastic deformation capacity by recourse to grain size and texture controlling<br>Build the principle of Mg alloy design and preparation<br>Develop Mg alloy development systems with various combinations between strength, toughness and processing technologies |

### 2.3 Other projects supported by Central Government

The other programs, which support the R&D activities for wrought magnesium alloys, mainly include the National Natural Science Foundation of China (NSFC), the National High-tech R&D Program (863 Program), the R&D Infrastructure and Facility Development Program and the International Collaboration Program.

In recent eight years, the National Natural Science Foundation of China (NSFC) has supported 99 projects in the field of magnesium and its alloys, and about 60% of these projects are focused on wrought magnesium alloys. Among them, forming technology is always a comparatively active research field. These projects were carried out mainly by Chongqing University, Institute of Metal Research of Chinese Academy of Sciences, and Shanghai Jiao Tong University. The research contents on welding, forming, casting and solidification for wrought magnesium alloys supported by NSFC are shown in Table 3.

**Table 3** Main research contents of projects funded by NSFC

| Project | Main research content |
|---|---|
| Casting and solidification | Electromagnetism-suspension continuous foundry<br>Thixotropic forming<br>Slurring-die forging dual control precise forming<br>Ultrasonic excitation or intensive electromagnetic field casting and its solidification behavior |
| Forming technology | Repeated unidirectional bending<br>SPF/DB composite forming<br>Reciprocating extrusion<br>Warm forming |
| Welding technology | Pack rolling welding<br>Friction stir welding |
| New alloys | Hydrogen-storage materials<br>Biomaterials<br>Metal glass and quasicrystal reinforced magnesium alloy<br>Damping materials and composite |

The National High-tech R&D Program (863 Program) was set up in 1986 to meet the global challenges of new technology revolution and competition. The main projects on wrought magnesium alloys during 2000−2009 under the National High-tech R&D Program included “Development and Application of High-performance Wrought Magnesium Alloys”, “Twin Roll Casting of Wrought Magnesium Alloys” and “Fabrication Technologies for Mg sheets”, which were carried out by Chongqing University and Shanghai Jiao Tong University.

Under the R&D Infrastructure and Facility Development Program, the National Engineering Research Center for Magnesium Alloys (CCMg) (led by PAN Fu-sheng) had been approved and was set up in Chongqing University in 2007. So far, no State Key Laboratories for magnesium and its alloys have been set up yet. CCMg has a creative research group of strong academic and engineering background. There are more than 160 researchers in the center, including 25 professors and about 120 research students. More than 60% of the professors and lecturers have the experiences of studying and working in West Europe and North America. In 2008, the National Joint Research Center for International Collaboration of Magnesium Alloys and Microsystems was set up in Chongqing University, which is also the only one of magnesium and its alloys in China.

There are two important international cooperation projects being carried out. One is “Canada−China−USA Collaborative Project on Magnesium Front End Research and Development" (organized by SHI Wen-fang, China Nonferrous Metals Industry Association), and the other is "China-German and China-Russia Collaborative Project on Wrought Magnesium Alloys" (organized by PAN Fu-sheng, Chongqing University).

## 3 Development of new wrought magnesium alloys in China

In Chongqing University, the researches on new types of wrought magnesium alloys mainly focus on the Mg-Gd-Y-Mn, Mg-Zn-Zr-RE, Mg-Zn-Mn-RE, Mg-Al-Zn-Sr and Mg-Li systems[1−9]. The mechanical properties of some of these alloys are shown in Table 4. The phase diagram investigation related to the development of new types of wrought alloys has being carried out, and the thermodynamic database in the Mg-Al-Zn-Y-Ce system has been developed[10].

In Shanghai Jiao Tong University, the researches on new types of wrought magnesium alloys mainly focus on the Mg-Gd-Dy-Nd-Zr, Mg-Gd-Nd-Zr, Mg-Gd-Y-Zr, Mg-Y-Sm-Zr and Mg-Zn-Nd-Zr alloys[10−21]. The mechanical properties of some of these alloys are shown in Table 5. It is seen from Table 5 that the Mg-12Gd-3Y-0.5Zr alloy exhibits relatively high mechanical properties.

In the Institute of Metal Research of Chinese Academy of Sciences, the researches on new types of wrought magnesium alloys mainly focus on the Mg-Gd-Y-Zr, Mg-Zn-Y-Zr, Mg-Y-Nd，Mg-Zn-Gd alloys and the super light Mg-Li-Zn-Y alloys[22−37]. The mechanical properties of some of these alloys are shown in Table 6. It is seen from Table 6 that the Mg-10Gd-3Y-1Zn-0.5Zr alloy exhibits relatively high

**Table 4** Mechanical properties of some of new types of wrought magnesium alloys developed in Chongqing University[1−9]

| Experimental alloy | State | Mechanical properties at RT | | |
|---|---|---|---|---|
| | | UTS/MPa | YS/MPa | $\delta$/% |
| Mg-10Gd-5Y-0.6Mn-1.0Zr | As-extruded | 324 | 286 | 4.29 |
| | As-extruded-T5(225 °C, 18 h) | 411 | 388 | 3.48 |
| Mg-10Gd-5Y-0.6Mn-0.4Sc | As-extruded | 314 | 282 | 4.68 |
| | As-extruded-T5(225 °C, 18 h) | 406 | 385 | 3.41 |
| Mg-10Gd-5Y-0.6Mn-0.3Ca | As-extruded | 330 | 278 | 4.04 |
| | As-extruded-T5(225 °C, 18 h) | 421 | 396 | 3.11 |
| Mg-6Zn-0.45Zr-0.7Sc | As-extruded | 350 | 278 | 14 |
| | As-extruded-T6((450 °C, 3 h)+(180 °C, 24 h)) | 360 | 352 | 10 |
| Mg-2Zn-1Mn-0.1Ce | As-extruded | 256 | 176 | 21 |
| Mg-2Zn-1Mn-0.1Ce | As-extruded | 236 | 143 | 32 |
| Mg-1.5Zn-0.5Zr-0.1Nd | As-extruded | 232 | 154 | 32 |
| Mg-7Y-0.5Zr | As-extruded | 280 | 183 | 29 |
| Mg-9Zn-0.6Zr-0.5Er | As-extruded | 366 | 313 | 22 |
| | As-extruded-T5(200 °C, 10 h) | 372 | 342 | 18 |
| Mg-1.5Zn-0.6Zr-4Er | As-extruded | 271 | 231 | 30 |
| Mg-8Zn-0.6Zr-1Y | As-extruded | 360 | 320 | 19 |

RT—Room temperature; UTS—Ultimate tensile strength; YS—Yield strength.

**Table 5** Mechanical properties of some of new types of wrought magnesium alloys developed in Shanghai Jiao Tong University[10−21]

| Experimental alloy | State | Mechanical properties at RT | | |
|---|---|---|---|---|
| | | UTS/MPa | YS/MPa | $\delta$/% |
| Mg-4Gd-3.5Dy-3.1Nd-0.4Zr | T6((525 °C, 8 h)+(200 °C, 64 h)) | 298 | 179 | 3.3 |
| Mg-llGd-2Nd-0.5Zr | T6((525 °C, 4 h)+(200 °C, 24 h)) | 336 | 222 | 2.5 |
| | T6((525 °C, 4 h)+10% cold deformation+(200 °C, 24 h)) | 381 | 298 | 1.4 |
| Mg-12Gd-3Y-0.5Zr | As-rolled | 362 | 250 | 6.02 |
| | As-rolled +T5(200 °C, 16 h) | 436 | 275 | 4.37 |
| Mg-4Y-4Sm-0.5Zr | As-cast | 222 | 128 | 6.2 |
| | T4(525 °C, 8 h) | 236 | 127 | 14.1 |
| | T6((525 °C, 8 h)+(200 °C, 16 h)) | 338 | 216 | 6.9 |
| Mg-5Zn-1Nd-0.4Zr | As-rolled | 319 | 278 | 10.8 |
| Mg-5Zn-2Nd-1.5Y-0.6Zr-0.4Ca | As-extruded | 357 | 351 | 1.92 |

RT—Room temperature; UTS—Ultimate tensile strength; YS—Yield strength.

mechanical properties, Mg-Li-Zn-Y alloy exhibits the best specific strength and Mg-2Zn-1Gd alloy exhibits good ductility at room temperature.

In Changchun Institute of Applied Chemistry of Chinese Academy of Sciences, the researches on new types of wrought magnesium alloys mainly focus on the Mg-Gd-Er-Zr, Mg-Gd-Ho-Zr, Mg-Gd-Y-Nd, Mg-Zn-Y-Al and Mg-Gd-Dy-Zr alloys[38−44]. Table 7 lists the mechanical properties of some of these alloys. It can be seen that the tensile strength of these alloys is normally between 200 MPa and 300 MPa.

In Central South University (CSU), the researches on new types of wrought magnesium alloys mainly focus on the Mg-Zn-Y-Zr, Mg-Yb-Zr, Mg-Zn-Nd-Y-Zr and Mg-Gd-Y-Zr(Mn) alloys[45−51]. Table 8 lists the mechanical properties of some of these alloys.

In other universities and institutes of China, such as Beijing General Research Institute for Nonferrous Metals and Xi'an Technological University of China, the researches on new types of wrought magnesium alloys mainly focus on the Mg-Gd-Y-Zn-Zr[52−53], Mg-Gd-Y-Nd-Zr[54], Mg-Y-Nd-Zr[55] alloys. Table 9 lists the mechanical properties of some of these alloys. It can be seen from Table 9 that the Mg-12Gd-4Y-1Zn-

**Table 6** Mechanical properties of some of new types of wrought magnesium alloys developed in the Institute of Metal Research of Chinese academy of sciences[22−37]

| Experimental alloy | State | Mechanical properties at RT | | |
|---|---|---|---|---|
| | | UTS/MPa | YS/MPa | $\delta$/% |
| Mg-10Gd-3Y-0.5Zr | As-extruded | 290 | 192 | 13 |
| | Extruded-T5 (250 °C, 10 h) | 341 | 228 | 11 |
| | Extruded-T5 (200 °C, 100 h) | 397 | 311 | 5.0 |
| Mg-10Gd-3Y-1Zn-0.5Zr | As-extruded | 347 | 231 | 11 |
| | Extruded-T5 (250 °C, 10 h) | 382 | 255 | 9.0 |
| | Extruded-T5 (200 °C, 100 h) | 428 | 339 | 4.0 |
| Mg-5.8Zn-1.0Y-0.48Zr | As-rolled (rolling temperature 320 °C) | 320 | 249 | 18 |
| | As-rolled (rolling temperature 350 °C) | 322 | 253 | 13 |
| | As-rolled (rolling temperature 380 °C) | 338 | 273 | 11 |
| Mg-12Zn-1.2Y-0.4Zr | As-extruded | 320 | 231 | 13 |
| Mg-5Y-4Nd | As-extruded-T5(200 °C, 72 h) | 351 | 274 | 7 |
| Mg-8Li-3Zn-0.5Y | As-extruded | 222 | 148 | 30.7 |
| Mg-8Li-6Zn-1Y | As-extruded | 239 | 159 | 20.4 |
| Mg-8Li-9Zn-1.5Y | As-extruded | 247 | 166 | 17.1 |
| Mg-1Zn-1Gd | As-rolled | 232 | 182 | 29.2 |
| Mg-2Zn-1Gd | As-rolled | 249 | 164 | 36.4 |

RT—Room temperature; UTS—Ultimate tensile strength; YS—Yield strength.

**Table 7** Mechanical properties of some of new types of wrought magnesium alloys developed in Changchun Institute of Applied Chemistry of Chinese academy of sciences[38−44]

| Experimental alloy | State | Mechanical properties at RT | | |
|---|---|---|---|---|
| | | UTS/MPa | YS/MPa | $\delta$/% |
| Mg-8.2Gd-2.8Er-0.34Zr | As-cast | 210 | 101 | 5.3 |
| | T6((530 °C, 10 h)+(230 °C, 100 h)) | 261 | 173 | 5.1 |
| Mg-8.1Gd-2.81Ho-0.38Zr | T6((530 °C, 10 h)+(230 °C, 60 h)) | 279 | 175 | 4.7 |
| Mg-12Gd-4Y-2Nd-0.3Zn-0.6Zr | As-cast | 275 | 220 | 3.1 |
| | T6((525 °C, 12 h)+(225 °C, 48 h)) | 310 | 280 | 2.8 |
| Mg-8Gd-2Nd-1Y-0.6Zr | As-cast | 261 | 188 | 9.4 |
| | T6((530 °C, 10 h)+(230 °C, 100 h)) | 293 | 221 | 4.6 |
| Mg-12.3Zn-5.8Y-1.4Al | As-cast | 191 | 100 | 6.9 |
| | T6((335 °C, 12 h)+(200 °C, 5 h)) | 203 | 106 | 4.9 |
| Mg-8.31Gd-1.12Dy-0.38Zr | As-cast | 210 | 187 | 5.7 |
| | T6((530 °C, 10 h)+(230 °C, 100 h)) | 355 | 261 | 3.8 |

RT—Room temperature; UTS—Ultimate tensile strength; YS—Yield strength.

**Table 8** Mechanical properties of some of new types of wrought magnesium alloys developed in Central South University[45−51]

| Experimental alloy | State | Mechanical properties at RT | | |
|---|---|---|---|---|
| | | UTS/MPa | YS/MPa | $\delta$/% |
| Mg-4.9Zn-0.9Y-07Z | As-rolled (rolling temperature 400 ˚C) | 365 | 305 | 4.0 |
| Mg-5Yb-0.5Zr | As-cast | 189 | 106 | 7.5 |
| | As-extruded | 304 | 268 | 12.9 |
| Mg-6Zn-2Nd-1Y-0.5Zr | As-extruded+rolling | 359 | 238 | 13.0 |
| | As-extruded+rolling+T5 (150 ˚C, 22 h) | 350 | 281 | 13.0 |
| Mg-9Gd-4Y-0.65Mn | As-extruded+T6 (520 ˚C, 2 h+150 ˚C, 24 h) | 336 | 310 | 11.2 |
| | As-extruded+T5 (225 ˚C, 24 h) | 360 | 320 | 5.0 |
| Mg-9Gd-4Y-0.6Zr | As-extruded+T6 (480 ˚C, 2 h+150 ˚C, 24 h) | 320 | 298 | 4.5 |
| | As-extruded+T5 (225 ˚C, 24 h) | 370 | 350 | 3.5 |

RT—Room temperature; UTS—Ultimate tensile strength; YS—Yield strength.

**Table 9** Mechanical properties of some of new types of wrought magnesium alloys developed in other universities and institutes of China[52−55]

| Experimental alloy | State | Mechanical properties at RT | | |
|---|---|---|---|---|
| | | UTS/MPa | YS/MPa | $\delta$/% |
| Mg-12Gd-4Y-1Zn-0.5Zr | As-cast | 238 | − | 7.6 |
| | As-extruded | 328 | − | 13.8 |
| | As-extruded-T5(200 ˚C, 70 h) | 463 | − | 6.1 |
| Mg-9Gd-3Y-0.6Zn-0.5Zr | As-cast | 230 | 170 | 7.0 |
| | As-extruded | 297 | 208 | 17.6 |
| | As-extruded-T5 (200 ˚C, 63 h) | 430 | 375 | 9.5 |
| | As-extruded-T5 (200 ˚C, 126 h) | 407 | 320 | 14.3 |
| Mg-7Gd-5Y-1.3Nd-0.5Zr | As-cast | 210 | 172 | 3.5 |
| | As-extruded-T5 (250 ˚C, 5 h) | 411 | 322 | 10.3 |
| Mg-4Y-3Nd-0.5Zr | As-cast | 190 | 132 | 6.5 |
| | As-extruded | 260 | 200 | 12.0 |
| | As-extruded-T5 (250 ˚C, 16 h) | 310 | 265 | 7.5 |

RT—Room temperature; UTS—Ultimate tensile strength; YS—Yield strength.

0.5Zr alloy exhibits relatively high mechanical properties.

## 4 Development of novel plastic processing technologies for wrought magnesium alloys

Since there are only two independent slip systems available, magnesium exhibits limited formability near room temperature. Furthermore, strong deformation texture, {0001} basal texture, readily exists in rolled or extruded products, which is detrimental to post-processing performances and service behaviors as well. Recently, great efforts have been put on the improvement of plasticity and formability of wrought magnesium alloys, through both alloy modification/ design and development of novel plastic processing technologies.

Twin-roll strip casting (TRC), which combines casting and hot rolling into a single step and provides much faster solidification rates than conventional casting, has still been receiving much concern. Besides the reduced degree of dendritic segregation and more homogeneous microstructure, TRC offers much fine grains. In fine-grained alloy, grain boundary sliding can act as an additional slip system, thus providing alloy an excellent ductility[56]. A lot of works are being carried out on both vertical and horizontal twin roll casting.

In Chongqing University, a new vertical twin roll casting device using refractory material has recently been built[57], as shown in Fig.1. Compared with conventional vertical casting, this new device can get more stable casting process and effectively improve the surface quality of magnesium alloy thin strip, as shown in Fig.2.

While the vertical TRC is still being developed in labs, a mass production line of horizontal TRC for magnesium alloys has been established in China. This line can produce thin strips of 200−600 mm in width and 2−8 mm in thickness. To further improve the microstructure of the strip, online large-reduction hot-rolling (Fig.3), immediately following the twin roll

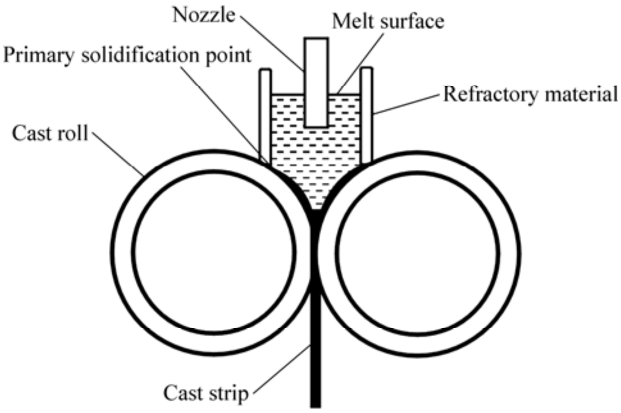


**Fig.1** Schematic diagram of new vertical twin roll casting device developed in Chongqing University, China

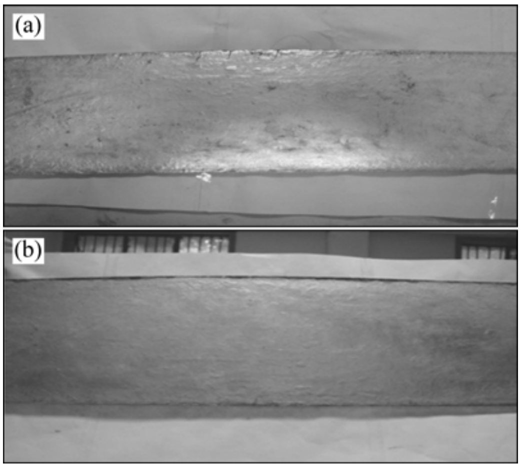


**Fig.2** Surfaces of AZ31 thin strips prepared by vertical twin roll casting without (a) and with (b) refractory material

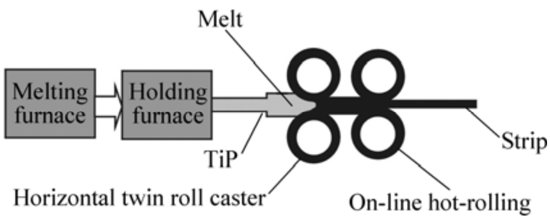


**Fig.3** Mass production line of horizontal twin roll casting and subsequent online hot rolling of magnesium alloy strips

casting, was developed and put into practice in Yinguang Mg Group of China, which can also make full use of the remaining heat and cut down the production cost. Through this online hot rolling, fine and uniform microstructure with less than 3 mm in thickness can be obtained. Subsequent online coiling of the strips can also be realized, as shown in Fig.4.

However, TRC suffers a strong basal texture. Recently, a combined new technology of TRC with the so-called differential speed rolling (DSR) was developed in South China University of Technology and Chongqing University. Preliminary results showed an effective

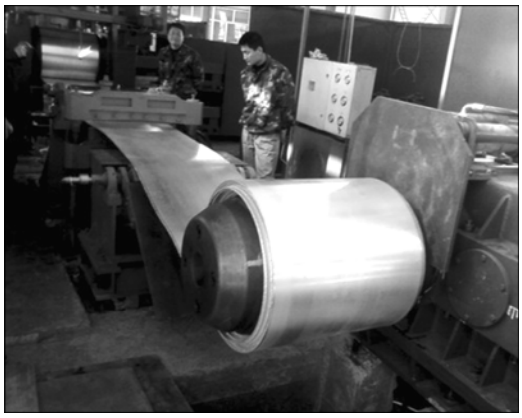

**Fig.4** Online coiling of Mg strip

plasticity enhancement due to the weakening of basal texture[58].

LIU et al[59] from Xi’an University of Architecture and Technology have tried a method called continuously changed section cyclic extrusion, as schematically shown in Fig.5, in which cylinder billet is subjected to repeated extrusion and forging, with 180˚ reversal of direction. Grain size is remarkably decreased through this severe plastic deformation (SPD). After 6-cycle processing for AZ31 alloy at 350 ˚C, the grain size was refined to 4 μm. In recent years, many kinds of new techniques based on SPD turn up, such as changed channel angular extrusion

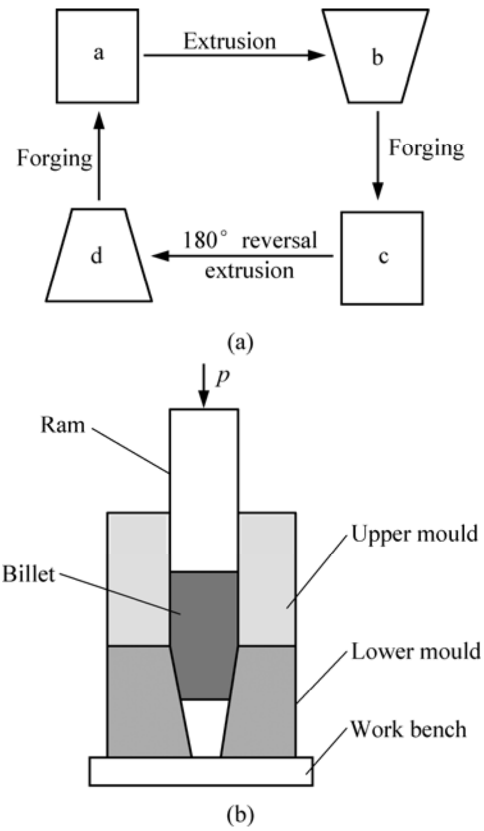


**Fig.5** Schematic diagram of processing route (a) and device of continuously changed section cyclic extrusion (b)

(CCAE) and double direction extrusion (DDE) developed in Chongqing University[60−61]. Take the DDE for example, grain size could be reduced from 400 μm in the as-cast state to 6 μm after extrusion.

Recently, a new method called Repeated Unidirectional Bending (RUB) has been developed in Chongqing University[62−63], which has shown great potential in the improvement of plasticity and stamping formability of commercial AZ31B magnesium alloy sheets at room temperature. Fig.6 illustrates the apparatus for RUB. It is found that in the sheets that have undergone RUB, the *c*-axis tended to become inclined from the normal direction (ND) towards the rolling direction (RD), and the $\{10\bar{1}2\}$ extension twinning was activated during bending. As a result, the texture components became more dispersed along the RD in the as-annealed sheets, leading to a considerably improved ductility at room temperature. The elongation to fracture and Erichsen value were increased to 38% and 67%, respectively. By using the RUB sheets of AZ31B magnesium alloy, cell phone houses have been successfully stamped in crank press at room temperature. This method provided an alternative to the electronic industry in the application of magnesium alloys.

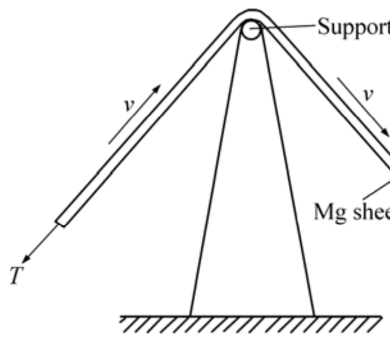


**Fig.6** Schematic illustration of apparatus for repeated unidirectional bending (RUB)

## 5 Summary

Because wrought magnesium alloys are so potential, researchers in China has begun to pay more attention to the development and application of wrought magnesium alloys and their processing technologies recently. A lot of R&D projects on wrought magnesium alloys have been funded mainly by the Ministry of Science & Technology of China and the National Natural Science Foundation of China. Many universities and institutes, such as Chongqing University, Shanghai Jiao Tong University, the Institute of Metals of Chinese Academy of Sciences, and Beijing General Research Institute for Nonferrous Metals, have joined these projects. A lot of new types of wrought magnesium alloys with additions of Gd, Y, Nd or Sr have been developed, and some novel processing technologies for wrought magnesium alloys are being investigated, some of which are very potential.

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