# High Plasticity Magnesium Alloys

### **FUSHENG PAN**

Chinese Academy of Engineering, Beijing, P.R. China National Engineering Research Center for Magnesium alloys (CCMg), Chongqing University, Chongqing, P.R. China

### **BIN JIANG**

National Engineering Research Center for Magnesium alloys (CCMg), Chongqing University, Chongqing, P.R. China

### JINGFENG WANG

National Engineering Research Center for Magnesium alloys (CCMg), Chongqing University, Chongqing, P.R. China

### YAOBO HU

National Engineering Research Center for Magnesium alloys (CCMg), Chongqing University, Chongqing, P.R. China

## **SUQIN LUO**

School of Materials Science and Engineering, Chongqing Jiaotong University, Chongqing, P.R. China



# **Contents**

Pre	face			i.			
1.	Overview						
	1.1	High-plasticity magnesium alloys and their processing technologies					
	1.2						
	1.3	MgZn alloys					
	1.4	Mg—Mn alloys					
		1.4.1	Mg—RE alloys	10			
		1.4.2	. Mg—Li alloys	1			
			Mg—Sn alloys	12			
		1.4.4	Processing technologies of high plastic magnesium alloys	13			
		1.4.5	Influence factors to the plasticity of magnesium alloys	16			
	1.5	Text	ure	23			
		1.5.1	Deformation mechanisms of magnesium alloys	24			
		1.5.2	Properties the Characterization of plastic deformation of magnesium alloys	31			
	1.6	Macrotexture					
	1.7		Microtexture				
			Static tensile test	35			
			Evaluation of anisotropy	36			
	1.8 Asymmetry of tension and compression						
	1.9 Anisotropy of mechanical properties						
	1.10		ic strain ratio and plane anisotropy coefficient	37 38			
	1.10.1 Erichsen drawing test						
	Furth	ner rea	ding	38			
2.	"Sol	id so	lution strengthening and ductilizing" theory for magnesium alloys	47			
	2.1	Alloy	design theory of solid solution strengthening and ductilizing	47			
	2.2	Theor	etical calculation of solid solution strengthening and ductilizing	49			
		2.2.1	Effect of alloying elements on stacking fault energy	50			
		2.2.2	Stacking fault energy (/2) for the basal plane of Mg	51			
		2.2.3	Effect of alloying elements on generalized stacking fault energy	54			
		2.2.4	Effect of alloying elements on critical resolved shear stress	55			
		2.2.5	Calculation methods for critical resolved shear stress	56			
		2.2.6	Site preferences of alloying elements in Mg crystal	59			
2.3		Experimental verification for the site preferences of alloying elements by X-ray diffraction					
		2.3.1	Calculation of theoretical critical shear strength	66			
		2.3.2	Calculation of modified stacking fault energy and critical resolved shear stress	69			

Cor	itents				
	2.4	Experi	mental verification of solid solution strengthening and ductilizing	73	
	2.5 Application of solid solution strengthening and ductilizing				
	2.6	Summ	nary	77	
		79			
	Furt	her rea	ding	79	
3.	. Ultrahigh plasticity Mg—Gd—Zr alloy				
	3.1	Micros	structure and properties of as-cast Mg—Gd—Zr alloy	83	
		3.1.1	Effect of Gd content on microstructure and properties	83	
		3.1.2	Effect of Gd addition on lattice parameters of as cast alloy matrix	85	
	3.2	Micros	structure and properties of as-quenched alloy	86	
		3.2.1	Effect of solution temperature on microstructure and properties of Vk61 alloy	86	
		3.2.2	Effect of Gd content on microstructure and properties of as-quenched Mg—xGd—0.6Zr alloy	89	
	2 2	Micro	structures and mechanical properties of extruded Mg—Gd—Zr alloy	94	
	ر.ر	3.3.1	Effect of pretreatment on microstructure and mechanical properties of extruded	24	
		3.3.1	Mg—xGd—0.6Zr alloy	94	
		3.3.2	Effect of Gd addition on lattice parameters of extruded alloys	97	
	3.4	High	plasticity mechanism of Mg—Gd—Zr alloy	99	
		3.4.1	Microstructure and plasticity of as-cast and extruded VK21 alloys	99	
		3.4.2	Effect of extrusion process on microstructure and plasticity of VK21 alloy	104	
		3.4.3	Effect of heat treatment on microstructure and plasticity of Vk21 alloy	111	
	3.6	Sumn	nary	114	
	References				
	Furt	her rea	ding	115	
4.	Me	dium-	strength and high-plasticity Mg—Mn-based alloys	119	
	4.1	Micro	structures and properties of Mg—Mn-based alloy	119	
		4.1.1	Effect of Mn on microstructures of Mg—Mn-based alloy	119	
		4.1.2	Effect of Mn on mechanical properties of Mg—Mn alloys	126	
		4.1.3	Effect of Mn on fracture surfaces of Mg—Mn alloys	129	
	4.2	Effect	of AI on the microstructure and mechanical properties of Mg—1Mn—AI alloy	129	
		4.2.1	Effect of AI on the microstructure of Mg-1Mn-AI alloy	130	
		4.2.2	Effect of AI on the mechanical properties of Mg-1Mn-AI alloy at room		
			temperature	135	
			Fracture surfaces	137	
	`		Effect of minor AI on microstructures of Mg—1Mn—AI Alloy	138	
			Effect of minor AI on mechanical properties of Mg-1Mn-AI alloy	146	
	4.3		of Y on microstructures and properties of Mg—1Mn—Y alloy	151	
		4.3.1	Effect of Y on the microstructure of Mg—1Mn—Y alloy	151	
			Effect of Y on the mechanical properties of Mg—1Mn—Y alloy	152	
		4.3.3	Fracture surface .	155	

**4.3.3** Fracture surface

	4.4	The mechanism of high plasticity of Mg—Mn alloy and the influence of aluminum and yttrium				
		,	Analysis on the formation of microstructures of Mg—Mn alloys	156 156		
			High-plasticity mechanism of Mg—Mn alloy	158		
			Effect of alloying elements aluminum and yttrium	160		
	4.5	Sumn	•	161		
		her rea		163		
			<b>3</b>			
5.	Me	dium-	strength and high-plasticity Mg—Sn-based alloys	167		
	5.1	Micro	structure and property of extruded Mg—Sn alloy	167		
	5.2	Phase	diagram and alloy design of Mg—Al—Sn alloy	170		
		5.2.1	Construction and verification of phase diagram	174		
		5.2.2	Alloy design	179		
	5.3	Micro	structure and property of the Mg—Al—Sn—Mn cast alloy	185		
		5.3.1	Phase composition and microstructure of Mg—Al—Sn—Mn alloy	185		
		5.3.2	Property of the as-cast Mg—Al—Sn—Mn alloy	196		
		5.3.3	Effect of Sn on the microstructure and property of AM alloy	200		
	5.4	Micro	structure and property of the wrought Mg—Al—Sn—Mn alloy	207		
		5.4.1	Effect of AI on the microstructure and property of the as-extruded Mg—AI—Sn—Mn alloy	207		
		5.4.2	Effect of Sn on the microstructure and property of as-extruded Mg—Al—Sn—Mn alloy	220		
		5.4.3	Effect of extrusion temperature on the microstructure and property of the alloy	223		
	5.5	Hot deformation parameter and constitutive equation of Mg—Al—Sn—Mn alloy				
		5.5.1	Hot deformation parameter and constitutive equation of ATM110 alloy	231		
		5.5.2	Hot deformation parameter and constitutive equation of ATM130 alloy	235		
		5.5.3	Hot deformation parameter and constitutive equation of ATM310 alloy	237		
		5.5.4	Hot deformation parameter and constitutive equation of ATM330 alloy	240		
	5.6 Summary					
	Refe	rences		245		
6.	Mic	rostru	acture and mechanical properties of the high-strength			
	Mg-Gd-Y-Zn-Mn alloy					
	6.1					
		6.1.1	Microstructure of the as-cast Mg—Gd—Y—Zn—Mn alloy before and after homogenization annealing	247		
		6.1.2	Effect of extrusion ratio on the microstructure and mechanical properties of the extruded Mg—Gd—Y—Zn—Mn alloy bar	249		
		6.1.3	Microstructure and mechanical properties of the extruded Mg—Gd—Y—Zn—Mn alloy sheet	255		
		6.1.4	Aging treatment of the extruded Mg—Gd—Y—Zn—Mn alloy	256		

6	5.2	Effect of rolling on the microstructure and mechanical properties of the Mg—Gd—Y—Zn—Mn alloy		
		6.2.1	Exploration of rolling process parameters of the as-annealed Mg—Gd—Y—Zn—Mn alloy	260
		6.2.2	Rolling deformation of the homogenized annealed Mg—Gd—Y—Zn—Mn alloy and its microstructure and mechanical properties	265
		6.2.3	"Rolling+solid solution+rolling" process of as-cast Mg—Gd—Y—Zn—Mn alloy and its microstructure and mechanical properties	270
6	5.3	High-plasticity mechanism of Mg—Gd—Y—Zn—Mn alloy		279
		6.3.1	Effect of long-period stacking order structure phase	279
		6.3.2	Combined effects of LPSO phase and precipitation phase	285
		6.3.3	Effect of Mn element	287
6	6.4	Summary		290
F	References			291
Index	<b>(</b>			293