

**THERMOMECHANICAL PROCESSING AND
DEFORMATION BEHAVIOR OF BINARY Mg-Y
ALLOYS WITH VARIED Y CONCENTRATION**

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ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI**

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DEFORMATION BEHAVIOR OF BINARY Mg-Y
ALLOYS WITH VARIED Y CONCENTRATION**

by

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DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

Submitted

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CERTIFICATE

This is to certify that the thesis entitled “**Thermomechanical processing and deformation behavior of binary Mg-Y alloys with varied Y concentration**” being submitted by **Mr. Nooruddin Ansari** to the Indian Institute of Technology Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY**. This is a record of bonafide research work carried out by him under my supervision and guidance. The matter presented in this thesis has not been submitted, in part or in full to any other University or Institute for the award of any degree or diploma.

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Abstract

Magnesium (Mg) is the lightest structural metal with potential use in the automobile, aerospace, and electronics sectors. However, a major problem in developing products is that their low formability at the ambient temperature restricts their use. Changing alloy chemistry and optimizing the process routes are two primary ways to enhance mechanical properties. Addition of rare earth (RE) elements in Mg has proved to improve its properties. Yttrium (Y) is the most effective option among other rare earth elements because of its high solubility in Mg. Thus, detailed information about the deformation, recrystallization, textural behavior and optimum conditions of processing binary Mg-Y alloys is important for developing new Mg-RE based alloys. Therefore, in the present dissertation work, thermomechanical processing and deformation behaviours of binary Mg-Y alloys with varied Y concentrations were investigated. Firstly, the effect of Y addition on the deformation behaviour of the magnesium alloys was investigated using compression tests (room temp.) and rolling experiments (420 °C). Solutionized binary Mg-Y alloys (5 and 10 wt.%Y) were selected for the deformation. The addition of Y resulted in a tremendous increase in yield and ultimate strength. At room temperature, it was found that increasing the Y content switches the dominant twinning mode from $\{10\bar{1}2\}$ extension twins and $\{10\bar{1}1\} - \{10\bar{1}2\}$ double twins, to less commonly observed $\{11\bar{2}1\}$ extension twins. Whereas at high temperature, Y increment appeared to enhance $\{10\bar{1}1\} - \{10\bar{1}2\}$ double twinning. Annealing of deformed samples suggested that increasing the Y content substantially retards the recrystallization kinetics due to enhanced grain boundaries pinning. During annealing, weakening of texture was more significant in the Mg-5Y alloy. After recrystallization, Mg-5Y alloy could have better grain refinement than Mg-10Y with basal texture. Hence, Mg-5Y has emerged as an optimum alloy with adequate balance in terms of strength and cost factor. Therefore, further investigation of processing and optimization of the parameters was only done on the Mg-5Y binary alloy.

The effect of rolling routes and rolling strains on the mechanical properties of Mg-5Y binary alloy was examined. Samples were hot rolled with varying rolling routes (i.e., unidirectional rolling (UR), cross rolling (CR)) and rolling strain (10 % – 60 %). The results suggested that an increment in rolling strain increases the dynamically recrystallized (DRX) grains in both UR and CR specimens. Alternatively, CR samples showed finer grain size with a higher fraction of DRX grains than UR samples at fixed strain. Further, the mechanical properties of CR samples showed significant improvement over UR samples due to modified basal texture and more refined grains.

Lastly, the constitutive equation and the processing maps of Mg-5Y binary alloy have been generated using high-temperature compression tests at different strain rates. The results show that flow stress increases with decrease in temperature or increase in the strain rate and vice-versa. An Arrhenius-based equation was used to model the high-temperature flow stress of the alloy. Processing maps were further generated for two strains, 0.25 and 0.45, representing the strain near the peak stress and steady-state region, respectively. The strain rate and temperature range for the safe region were found to be $0.001 \text{ s}^{-1} - 0.1 \text{ s}^{-1}$ and $623 \text{ K} - 723 \text{ K}$ ($350 \text{ }^\circ\text{C} - 450 \text{ }^\circ\text{C}$), while for the unstable region, they were found to be $1 \text{ s}^{-1} - 10 \text{ s}^{-1}$ and $523 \text{ K} - 723 \text{ K}$ ($250 \text{ }^\circ\text{C} - 450 \text{ }^\circ\text{C}$). In the safe region, characterization of deformed microstructures using electron backscatter diffraction (EBSD) showed that the prominent deformation mechanism was continuous dynamic recrystallization (CDRX) and discontinuous dynamic recrystallization (DDRX) with the manifestation of twin induced DRX and particle stimulated nucleation (PSN). However, the unstable region consisted of cracks, voids, and deformation twins with little evidence of DRX.

सार

ऑटोमोबाइल, एयरोस्पेस और इलेक्ट्रॉनिक्स क्षेत्रों में संभावित उपयोग के साथ मैग्नीशियम (Mg) सबसे हल्का संरचनात्मक धातु है। हालांकि, विकासशील उत्पादों में एक बड़ी समस्या यह है कि परिवेश के तापमान पर उनकी कम फॉर्मैबिलिटी उनके उपयोग को प्रतिबंधित करती है। मिश्र धातु रसायन विज्ञान को बदलना और प्रक्रिया मार्गों को अनुकूलित करना यांत्रिक गुणों को बढ़ाने के दो प्राथमिक तरीके हैं। Mg में रेयर अर्थ (RE) तत्वों को मिलाने से इसके गुणों में सुधार हुआ है। Mg में इसकी उच्च घुलनशीलता के कारण अन्य दुर्लभ पृथ्वी तत्वों में Yttrium (Y) सबसे प्रभावी विकल्प है। इस प्रकार, नए Mg-RE आधारित मिश्र धातुओं को विकसित करने के लिए विरूपण, पुनः क्रिस्टलीकरण, बनावट व्यवहार और बाइनरी Mg-Y मिश्र धातुओं के प्रसंस्करण की इष्टतम स्थितियों के बारे में विस्तृत जानकारी महत्वपूर्ण है। इसलिए, वर्तमान शोध प्रबंध में, थर्मोमेकेनिकल प्रसंस्करण और बाइनरी एमजी-वाई मिश्र धातुओं के विरूपण व्यवहारों की विभिन्न वाई सांद्रता के साथ जांच की गई।

सबसे पहले, मैग्नीशियम मिश्र धातुओं के विरूपण व्यवहार पर वाई जोड़ के प्रभाव की जांच संपीड़न परीक्षण (कमरे का तापमान) और रोलिंग प्रयोगों (420 डिग्री सेल्सियस) का उपयोग करके की गई थी। सॉल्युज बाइनरी Mg-Y धातुओं (५ और १० वजन %Y) को विरूपण के लिए चुना गया था। Y के जुड़ने से उपज और परम शक्ति में जबरदस्त वृद्धि हुई। कमरे के तापमान पर, यह पाया गया कि Y सामग्री बढ़ने से प्रमुख ट्विनिंग मोड $\{10\bar{1}2\}$ एक्सटेंशन ट्विन्स और $\{10\bar{1}1\} - \{10\bar{1}2\}$ डबल ट्विन्स से कम सामान्य रूप से देखे जाने वाले $\{11\bar{2}1\}$ एक्सटेंशन ट्विन्स में बदल जाता है। जबकि उच्च तापमान पर, Y वृद्धि $\{10\bar{1}1\} - \{10\bar{1}2\}$ डबल ट्विनिंग को बढ़ाती हुई दिखाई दी। विकृत नमूनों की घोषणा ने सुझाव दिया कि वाई सामग्री में वृद्धि से अनाज की सीमाओं को बढ़ाने के कारण पुनर्रचना कैनेटीक्स में काफी कमी आई है। तपिश के दौरान, Mg-५Y मिश्र धातु में बनावट का कमजोर होना अधिक महत्वपूर्ण था। पुनः क्रिस्टलीकरण के बाद, Mg-५Y मिश्र धातु में बेसल बनावट के साथ Mg-10Y की तुलना में बेहतर अनाज शोधन हो सकता है। इसलिए, ताकत और लागत कारक के मामले में पर्याप्त संतुलन के साथ Mg-५Y एक इष्टतम मिश्र धातु के रूप में उभरा है। इसलिए, मापदंडों के प्रसंस्करण और अनुकूलन की आगे की जांच केवल Mg-५Y बाइनरी मिश्र धातु पर की गई थी।

Mg-५Y बाइनरी मिश्र धातु के यांत्रिक गुणों पर रोलिंग मार्गों और रोलिंग तनाव के प्रभाव की जांच की गई। नमूने अलग-अलग रोलिंग मार्गों (यानी, यूनिडायरेक्शनल रोलिंग (यूआर), क्रॉस रोलिंग (सीआर)) और रोलिंग तनाव (१०% - ६०%) के साथ हॉट रोल्ड थे। परिणामों ने सुझाव दिया कि रोलिंग स्ट्रेन में

वृद्धि से यूआर और सीआर दोनों नमूनों में गतिशील रूप से पुनः क्रिस्टलीकृत (डीआरएक्स) अनाज बढ़ जाता है। वैकल्पिक रूप से, सीआर नमूनों ने निश्चित तनाव पर यूआर नमूनों की तुलना में डीआरएक्स अनाज के उच्च अंश के साथ महीन दाने का आकार दिखाया। इसके अलावा, सीआर नमूनों के यांत्रिक गुणों ने संशोधित बेसल बनावट और अधिक परिष्कृत अनाज के कारण यूआर नमूनों में महत्वपूर्ण सुधार दिखाया।

अंत में, विभिन्न तनाव दरों पर उच्च तापमान संपीड़न परीक्षणों का उपयोग करके Mg-५Y बाइनरी मिश्र धातु के संवैधानिक समीकरण और प्रसंस्करण मानचित्र तैयार किए गए हैं। परिणाम बताते हैं कि तापमान में कमी या तनाव दर में वृद्धि के साथ प्रवाह तनाव बढ़ता है और इसके विपरीत। मिश्र धातु के उच्च तापमान प्रवाह तनाव को मॉडल करने के लिए एक अरहेनियस-आधारित समीकरण का उपयोग किया गया था। प्रसंस्करण मानचित्र आगे दो उपभेदों, ०.२५ और ०.४५ के लिए तैयार किए गए थे, जो क्रमशः चरम तनाव और स्थिर-राज्य क्षेत्र के पास तनाव का प्रतिनिधित्व करते हैं। सुरक्षित क्षेत्र के लिए तनाव दर और तापमान सीमा $0.001 \text{ s}^{-1} - 0.1 \text{ s}^{-1}$ और $623 \text{ K} - 723 \text{ K}$ ($350^\circ \text{C} - 450^\circ \text{C}$) पाई गई, जबकि अस्थिर क्षेत्र के लिए, वे पाए गए $1 \text{ s}^{-1} - 10 \text{ s}^{-1}$ और $423 \text{ K} - 723 \text{ K}$ ($150^\circ \text{C} - 450^\circ \text{C}$)। सुरक्षित क्षेत्र में, इलेक्ट्रॉन बैकस्कैटर विवर्तन (ईबीएसडी) का उपयोग करते हुए विकृत माइक्रोस्ट्रक्चर के लक्षण वर्णन से पता चला है कि प्रमुख विरूपण तंत्र निरंतर गतिशील पुनः क्रिस्टलीकरण (सीडीआरएक्स) और जुड़वां प्रेरित डीआरएक्स और कण उत्तेजित न्यूक्लियेशन (पीएसएन) की अभिव्यक्ति के साथ असंतत गतिशील पुनर्रचना (डीडीआरएक्स) था। . हालांकि, अस्थिर क्षेत्र में डीआरएक्स के बहुत कम सबूत के साथ दरारें, रिक्तियां और विरूपण ट्विनिंग शामिल थे।

Table of contents

CERTIFICATE.....	i
Acknowledgements	iii
Abstract.....	v
Table of contents	ix
List of figures.....	xv
List of tables.....	xxvii
Chapter 1 Introduction.....	1
Chapter 2 Literature review	5
2.1 Introduction.....	5
2.2 Crystallography of Magnesium.....	5
2.3 Common alloying elements	7
2.4 Deformation behavior of Mg	8
2.4.1 Slip	8
2.4.2 Twinning	10
2.4.3 Stress-strain behavior.....	17
2.5 Wrought Mg alloys	20
2.5.1 Texture	21
2.5.2 Yield anisotropy.....	22
2.5.3 Limited formability	23

2.6 Magnesium-rare earth (Mg-RE) alloys	24
2.6.1 Effect of RE on texture modification.....	24
2.6.2 Effect of RE on mechanical properties	28
2.6.3 Mg-Y alloys	30
2.7 Effect of strain path change (SPC) on deformation behavior of Mg alloys.....	31
2.7.1 Effect on microstructure and texture.....	31
2.7.2 Effect on mechanical properties.....	33
2.8 Recrystallization	35
2.8.1 Basics of recrystallization	35
2.8.2 Recrystallization in Mg alloys	36
2.8.3 Nucleation mechanism during recrystallization in Mg alloys	38
2.9 Constitutive analysis and processing maps of Mg-RE alloys.....	48
2.9.1 Effect of temperature and strain rate on flow behavior	48
2.9.2 Constitutive analysis	51
2.9.3 Processing maps.....	52
2.10 Summary	55
Chapter 3 Scope and Objectives	57
Chapter 4 Materials and Methodologies.....	59
4.1 Introduction.....	59
4.2 Materials Processing	59
4.3 Solutionization treatment	60

4.4 Hot rolling	62
4.5 Microstructural and texture characterization	63
4.5.1 Metallography	63
4.5.2 Optical Microscopy	65
4.5.3 Scanning electron microscopy	65
4.5.4 Electron backscattered diffraction (EBSD) analysis.....	66
4.5.5 Texture measurements	67
4.5.6 Dislocation density.....	68
4.6 Mechanical testing	69
4.6.1 Hardness test	69
4.6.2 Compression test.....	70
4.6.3 Tensile test	75
Chapter 5 Room temperature deformation behavior of Mg-Y binary alloys	77
5.1 Introduction.....	77
5.2 Initial microstructure.....	77
5.2.1 As-cast.....	77
5.2.2 Solution treatment.....	81
5.3 Compressive stress-strain curves	83
5.4 Microstructure evolution during deformation.....	85
5.5 Recrystallization behavior	93
5.6 Texture	102

5.7 Summary	104
Chapter 6 High temperature deformation behavior of Mg-Y binary alloys.....	105
6.1 Introduction.....	105
6.2 Hot rolled microstructures	105
6.3 Hardness evolution.....	108
6.4 Static recrystallization.....	109
6.5 Texture evolution	113
6.6 Tensile test	116
6.7 Summary	118
Chapter 7 Effect of rolling routes on the deformation behavior of Mg-5Y binary alloy	119
7.1 Introduction.....	119
7.2 Initial microstructure and texture.....	119
7.3 Microstructure evolution during hot rolling	120
7.4 Texture evolution during hot rolling.....	126
7.5 Tensile behavior of the hot-rolled alloy	129
7.6 Summary	133
Chapter 8 Constitutive analysis and processing maps of hot rolled Mg-5Y binary alloy	135
8.1 Introduction.....	135
8.2 Theory of constitutive analysis and processing maps.....	136
8.2.1 Basics of constitutive analysis	136

8.2.2 Basics of processing maps	138
8.3 Microstructure prior to compression.....	140
8.4 Flow stress behaviour	141
8.5 Constitutive Analysis	143
8.6 Processing Maps	145
8.7 Interpretation of processing maps	148
8.7.1 Stable region	148
8.7.2 Unstable region	152
8.8 Summary	154
Chapter 9 Conclusions and Future work.....	155
9.1 Conclusions.....	155
9.2 Future work.....	157

List of figures

Figure 2.1: Hard sphere model of hexagonal close packed structure.	6
Figure 2.2: (a) Hexagonal prism illustrating hexagonal close packed structure and (b) primitive hexagonal unit cell.	6
Figure 2.3: Illustrates different slip systems observed in Mg alloys. Note that the shaded planes denote the slip planes, and the arrows denote the slip directions.	8
Figure 2.4: CRSS value of different slip and twinning modes of pure Mg [8].....	10
Figure 2.5: Schematic of deformation twinning.	11
Figure 2.6: Twin system observed in magnesium alloys (a) extension twinning and (b) contraction twinning.....	13
Figure 2.7: CRSS of {1012} and {1121} extension twin with solute concentration [24].....	14
Figure 2.8: The variation of {1012} and {1121} twin boundary energy with the addition of Gd content [25].	15
Figure 2.9: Microstructure and basal pole figure of Mg-3Al-1Zn alloy deformed under in-situ tensile loading and unloading [26].....	16
Figure 2.10: Twin volume fraction of Mg-Al-Mn alloy during room temperature compression at different strains [27].....	17
Figure 2.11: Stress-strain characteristics of single crystal pure Mg in three different orientations. The inset schematic represents loading and constraints directions [30].	19
Figure 2.12: Yield loci of polycrystal pure Mg [30].....	20
Figure 2.13: EBSD IPF map of as-rolled AZ31 (a) along RD - TD plane and (b) along RD - ND plane. (c) {0001}, 1120 and 1010 pole figure illustrating the texture of as-rolled AZ31 alloy [41].....	21
Figure 2.14: Stress-strain of rolled AZ31 alloy. Note that RD, ND, t, and c denotes the rolling direction, normal direction, tension, and compression, respectively [43].	22

Figure 2.15: Forming limit diagram of Al 6061 [44] and AZ31 [45] alloy at room temperature.	23
Figure 2.16: ED IPF illustrating the texture of (a) non recrystallized AZ31, (b) non recrystallized ZC71, (c) non recrystallized WE43, (d) recrystallized AZ31, (e) recrystallized ZC71 and (f) recrystallized WE43 [49].	26
Figure 2.17: Basal pole figure of pure magnesium and binary Mg-RE alloys with low and high concentrations in as-rolled and annealed conditions [50]......	27
Figure 2.18: EBSD maps and respective inverse pole figures of deformed and recrystallized grain in Mg-Gd alloy extruded at 415 °C [51]......	27
Figure 2.19: Engg stress-strain of binary Mg-Gd alloys under tension at room temperature [55].	28
Figure 2.20: Room temperature compression curves of pure Mg and binary Mg-Y alloys [56].	29
Figure 2.21: EBSD IPF maps of Mg-0.6Zr alloys during (a) UR and (b) CR [67].	32
Figure 2.22: IPF of different directions of Mg-0.6Zr alloy (a, b, c and d) UR and (e, f, g and h) CR [67]......	32
Figure 2.23: Optical micrographs of Mg-Gd-Y-Zr alloy rolled (10%) via (a, b) CR and (c, d) UR [68].	33
Figure 2.24: Stress-strain of ME20 alloy in different directions rolled via (a) CR and (b) UR [70]......	34
Figure 2.25: Stress-strain of Mg-2Zn-2Gd alloy rolled and annealed (a) via CR and (b) via UR [62]......	34
Figure 2.26: Schematic of annealing phenomenon (a) deformed material, (b) recovery state (c) nucleation of recrystallized grains, (d) fully recrystallized grains, (e) growth of recrystallized grains and (f) abnormal grain growth of recrystallized grains [76].	36

Figure 2.27: Schematic drawing illustrating the mechanism of CDRX and DDRX [79].....	37
Figure 2.28: Nucleation mechanism proposed to be active in recrystallization of magnesium alloys.	38
Figure 2.29: Schematic of nucleation at grain boundaries during DRX of Mg-0.8Al during elevated temperature compression [81].	39
Figure 2.30: (a) Serrations of grain boundaries during DRX of AZ31 alloys (b) Fine DRX grains at higher magnification [82].	39
Figure 2.31: EBSD map showing evidence of grain boundary bulging in AZ31 compressed at high temperature [80].	40
Figure 2.32: Schematic illustration of recrystallization by subgrain boundary rotation nucleation mechanism [84].	41
Figure 2.33: EBSD IPF maps of extruded Mg-9.80Gd-3.78Y-1.12Sm-0.48Zr alloy illustrating subgrains (with LAGBS in grey color) and DRX grains (black color) via subgrain boundary rotation nucleation mechanism [87].	42
Figure 2.34: EBSD maps showing shear band nucleation in pure magnesium (a) IPF map and (b) Kernel average misorientation (KAM) map showing recrystallized grains. Note that the black region in the KAM map show matrix grains $\geq 2 \mu\text{m}$ and grain orientation spread (GOS) greater than 0.6° [61].	43
Figure 2.35: SEM and optical micrograph of twin induced recrystallization in AZ31 alloy [82].	44
Figure 2.36: Quasi-in situ EBSD maps illustrate twin induced recrystallization in WE43 alloy [21].	45
Figure 2.37: (a) Schematic illustrates the particle deformation zones adjacent to large second phase particle [75] and (b) nucleation of grains near the second phase particles in ZWEK 1000 Mg alloys [94].	47

Figure 2.38: Flow stress behavior at different temperatures (350 °C – 480 °C) and strain rates of (a) 0.001 s ⁻¹ , (b) 0.01 s ⁻¹ , (c) 0.1 s ⁻¹ , (d) 1 s ⁻¹ and (e) 10 s ⁻¹ [99].	49
Figure 2.39: Flow stress behavior of Mg-Zn-Gd-Er alloy at different strain rates (10 ⁻³ s ⁻¹ – 10 s ⁻¹) for a fixed temperature at (a) 380 °C, (b) 330 °C, (c) 280 °C, (d) 230 °C and (e) 180 °C [101].	50
Figure 2.40: Processing map of WE43 alloy at 0.65 strain [99].	53
Figure 2.41: Microstructure of WE43 alloys processed under (a) stable region and (b) unstable region [99].	53
Figure 2.42: Mg-Gd-Y-Nd-Zr alloy processing maps at the strain of (a) 0.1 and (b) 0.7 [98].	54
Figure 2.43: OM of Mg-Gd-Y-Nd-Zr alloy processed under (a) stable region and (b) unstable region [98].	54
Figure 4.1: Schematic depicting the steps involved in the preparation and processing of Mg–5Y and Mg–10Y.	60
Figure 4.2: Cast plates of (a) Mg-5Y and (b) Mg-10Y.	61
Figure 4.3: Mg-Y binary phase diagram (Mg rich side) [46]. The red lines denote 5 and 10 wt. % Y.	61
Figure 4.4: Schematic illustration of the solutionization treatment. Note that RT and WQ denote room temperature and water quenched.	62
Figure 4.5: Schematic diagram of UR and CR. Note that in each pass ~5 % thickness is reduced.	63
Figure 4.6: Schematic illustrating the steps involved in the preparation of specimen for metallographic analysis.	64
Figure 4.7: Photograph of electropolishing machine, Struers Lectropol 5.	65
Figure 4.8: Scanning electron microscope (SEM), JEOL JSM - 7800 F.	66

Figure 4.9: (a) XRD machine, Rigaku Ultima IV and (b) zoomed image of XRD chamber showing X-ray source, sample holder and detector.68

Figure 4.10: Schematic of Vickers hardness indentation.....70

Figure 4.11: Schematic diagram of room temperature compression sample (all dimensions are in mm). The CD, TD, and ND represent the sample casting, transverse, and normal directions, respectively. The compression axis is perpendicular to the ND direction.....71

Figure 4.12: Stress-strain for 0.2 % offset method.72

Figure 4.13: Schematic diagram for high temperature compression sample (all dimensions are in mm). The rolling direction, transverse direction, and normal direction of the sample are represented by the letters RD, TD, and ND, respectively. The compression axis is perpendicular to the RD direction.....74

Figure 4.14: Gleeble 3500 thermomechanical simulator, Dynamic System Inc. Poestenkill, NY.74

Figure 4.15: Tensile sample schematic diagram (all dimensions are in mm). The letters RD and TD stand for rolling and transverse direction, respectively. Note that the gauge length is parallel to the RD.75

Figure 4.16: Photograph of 30 kN UTM machine (Zwick) equipped with a video extensometer.76

Figure 5.1: OM of as-cast (a) Mg-5Y and (b) Mg-10Y.....78

Figure 5.2: SEM showing the initial microstructure of as-cast (a) Mg-5Y and (b) Mg-10Y. Note that the arrow shows the second phase present in as-cast material.....78

Figure 5.3: EDS spectra of as-cast material (shown in Figure 5.2) (a) Mg-5Y and (b) Mg-10Y. Note that the inset shows the zoomed image of the highlighted region.79

Figure 5.4: (a) SEM micrograph of a precipitate highlighted (golden box) by box in as-cast Mg-5Y (Figure 5.2) at high magnification, (c, d) EDS elemental area maps of the precipitate showing distribution of Mg and Y.....	80
Figure 5.5: EDS point spectrum of the second phase.	80
Figure 5.6: 2 θ XRD of the as-cast Mg-5Y.	81
Figure 5.7: 2 θ XRD of the solution treated Mg-5Y and Mg-10Y.	82
Figure 5.8: EBSD normal axis IPF maps of the alloys solution treated (a) Mg-5Y and (b) Mg-10Y.....	82
Figure 5.9: Room temperature compressive stress-strain curves for Mg-5Y and Mg-10Y alloy. Note that the arrows denote the strain levels (10 %, 20 % and ~ 30 %) for which the microstructural analysis has been subsequently presented, and cross denotes the fracture point.	84
Figure 5.10: Work hardening rate as a function of effective stress for room temperature compressed Mg-5Y and Mg-10Y alloy.	84
Figure 5.11: Band contrast (BC) maps superimposed with twin boundaries of Mg-5Y alloy compressed at (a) 10 % strain, (b) 20 % strain and (c) 30 % strain. Note that {1012} extension twin is characterized using 86° misorientation about $\langle 1120 \rangle (\pm 5^\circ)$, while 1011 – {1012} double twin is characterized using 38° misorientation about $\langle 1120 \rangle (\pm 5^\circ)$. The black and aqua lines denote high angle grain boundaries (HAGB) and low angle grain boundaries (LAGB) [124].	86
Figure 5.12: Schmid factor map for (a) {1012} extension twin at 10 % strain, (b) {1011} contraction twin at 20 % strain and (c) {1011} contraction twin at 30 % strain.	87
Figure 5.13: BC maps superimposed with twin boundaries of Mg-10Y alloy compressed at (a) 10 % strain, (b) 20 % strain and (c) 30 % strain. Note that {1012} extension twin is characterized using 86° misorientation about $\langle 1120 \rangle (\pm 5^\circ)$, while {1121} extension twin is	

characterized using 34° misorientation about $\langle 1010 \rangle (\pm 5^\circ)$. The black and aqua lines denote HAGB and LAGB, respectively.	88
Figure 5.14: Schmid factor maps for $\{1121\}$ extension twin at (a) 10 % strain, (b) 20 % strain and (c) 30 % strain.	89
Figure 5.15: Twin area fraction at different strain levels for (a) Mg-5Y and (b) Mg-10Y.	90
Figure 5.16: (a) CRSS of $\{1012\}$ extension twin at different Y concentration (b) Effect of Y concentration on ratios between CRSS for $\langle c+a \rangle$ pyramidal slip and CRSS for $\langle a \rangle$ basal slip in different Mg-Y alloys [128–132].	91
Figure 5.17: Microhardness evolution of Mg-5Y and Mg-10Y samples deformed up to 30% strain and then annealed at 400°C	94
Figure 5.18: EBSD IPF maps of annealed Mg-5Y (a) 2 min, (b) 4 min, (c) 8 min, and (d) 10 min, respectively.	95
Figure 5.19: (a) BC map superimposed with twin boundaries, (b) normal axis IPF map of Mg-10Y alloy deformed upto 30% strain and then annealed for 5 h at 400°C . Note that $\{1012\}$ extension twin is characterized using 86° misorientation about $\langle 1120 \rangle (\pm 5^\circ)$, while $\{1121\}$ extension twin is characterized using 34° misorientation about $\langle 1010 \rangle (\pm 5^\circ)$. The black and white lines denote HAGB and LAGB, respectively.	96
Figure 5.20: (a) BSE image showing precipitates at the twin boundaries (c1), grain boundaries (c2) and grain interior (c3). (b) EDS point spectrum of the precipitate formed inside the grain.	98
Figure 5.21: Microhardness evolution of Mg-10Y alloy (30% strained) and then annealed at 500°C	100
Figure 5.22: EBSD IPF maps for Mg-10Y alloy annealed at 500°C for (a) 10 min, (b) 15 min and (c) 20 min, respectively.	100

Figure 5.23: {0002} pole figures illustrating the texture of Mg-5Y (a) solution treated, (b) deformed up to 30 % strain, (c) annealed at 400 °C for 10 min, and Mg-10Y (d) solution treated, (e) deformed up to 30 % strain, (f) annealed at 500 °C for 20 min. The sample's casting direction, transverse direction, and normal direction are indicated by the letters CD, TD, and ND. It's worth noting that the compression direction is perpendicular to the centre of pole figure (i.e., along the ND direction). 103

Figure 6.1: Band contrast maps superimposed with twin boundaries of 40% hot-rolled samples (a) Mg-5Y, (b) Mg-10Y. Note that {1012} extension twin was characterized using 86° misorientation about <1210>, {1011} contraction twin was characterized using 56° misorientation about <1210> and {1011}-{1012} double twin was characterized using 38° misorientation about <1210>..... 106

Figure 6.2: EBSD IPF maps of 40% hot rolled (a) Mg-5Y and (b) Mg-10Y..... 107

Figure 6.3: Local average misorientation (LAM) maps of 40% hot-rolled (a) Mg-5Y and (b) Mg-10Y..... 108

Figure 6.4: Microhardness evolution of Mg-5Y and Mg-10Y alloys annealed at 400°C. Note that arrows indicate the hardness of as-rolled samples..... 109

Figure 6.5: EBSD IPF maps of annealed Mg-5Y (a) 5 min, (b) 20 min, and (c) 60 min. 110

Figure 6.6: EBSD IPF maps of annealed Mg-10Y alloy for (a) 5 min, (b) 20 min, and (c) 60 min. 111

Figure 6.7: Recrystallization fraction estimated from EBSD maps of annealed Mg-5Y and Mg-10Y..... 112

Figure 6.8: XRD pole figures illustrating the texture of Mg-5Y alloy in (a) as-rolled, (b) and (c) annealed (400 °C) for 20 min and 60 min, respectively. 113

Figure 6.9: XRD pole figures illustrating the texture of Mg-10Y alloy in (a) as-rolled, (b) and (c) annealed (400 °C) for 20 min and 60 min, respectively..... 114

Figure 6.10: Comparison of maximum basal pole intensity for hot rolled and annealed Mg-Y. The red and black arrows show the intensity of as-rolled alloys.....	115
Figure 6.11: Tensile true stress - true strain curves of as-rolled (AR) and annealed (Ann) Mg-5Y and Mg-10Y alloy.....	117
Figure 7.1: (a) EBSD normal axis IPF map and (b) XRD measured {0002} and {1010} PF of solution treated Mg-5Y prior to rolling.	120
Figure 7.2: XRD 2θ of the hot rolled Mg-5Y alloy after different amounts of rolling strain in (a) UR and (b) CR.....	121
Figure 7.3: EBSD IPF maps of hot rolled Mg-5Y alloy in UR for (a) 10 %, (b) 20 %, (c) 40 % and (d) 60 % rolling strain.	122
Figure 7.4: EBSD IPF maps of hot rolled Mg-5Y alloy by CR method for (a) 10 %, (b) 20 %, (c) 40 % and (d) 60 % rolling strains.....	123
Figure 7.5: Band contrast maps superimposed with twin boundaries of Mg-5Y alloy hot rolled at (a) 10 % strain via UR, (b) 40 % strain via UR, (c) 10 % via CR, and (d) 40 % strain via CR. Note that {1012} extension twin is characterized using 86° misorientation about < 1120 > (±5°), while 1011 – {1012} double twin is characterized using 38° misorientation about < 1120 > (±5°).	126
Figure 7.6: Macro-texture, as determined by XRD, showing the {0002} pole figures of Mg-5Y alloy post hot rolling by UR method for (a) 10 %, (b) 20 %, (c) 40 %, and (d) 60 % rolling strains.	128
Figure 7.7: Macro-texture, as determined by XRD, showing the {0002} pole figures of Mg-5Y alloy post hot rolling by CR method for (a) 10 %, (b) 20 %, (c) 40 %, and (d) 60 % rolling strains.	129
Figure 7.8: Engineering stress-strain of hot rolled Mg-5Y at different strains obtained via (a) UR and (b) CR methods.....	130

Figure 7.9: Comparison of tensile properties of Mg-5Y hot-rolled at different strains by UR and CR methods (a) YS, (b) UTS and (c) elongation.	131
Figure 8.1: Optical micrograph of hot rolled and annealed Mg-5Y alloy prior to compression.	140
Figure 8.2: An EBSD compression axis IPF map of hot rolled and annealed Mg-5Y alloy before compression.	141
Figure 8.3: True stress-strain of Mg-5Y at (a) 0.001 s^{-1} , (b) 0.1 s^{-1} , (c) 1 s^{-1} and (d) 10 s^{-1} . ..	142
Figure 8.4: Peak stress as a function of temperature and strain rates.	143
Figure 8.5: Plots between (a) $\ln \epsilon$ vs. $\ln \sigma$, (b) $\ln \epsilon$ vs. σ , (c) $\ln \epsilon$ vs. $\ln[\sinh(\alpha\sigma)]$, and (d) $\ln[\sinh(\alpha\sigma)]$ vs. $1/T$	144
Figure 8.6: Plot between $\ln[\sinh(\alpha\sigma)]$ vs $\ln Z$	145
Figure 8.7: Processing maps of Mg-5Y alloy at 0.25 strain. Domains I and II are the safe regions, whereas domains III and IV are the unstable regions. The colour scale represents the magnitude of power dissipation efficiency (%).	146
Figure 8.8: Processing maps of Mg-5Y alloy at 0.45 strain. Domains I and II are the safe regions, whereas domains III and IV are the unstable regions. The colour scale represents the magnitude of power dissipation efficiency (%).	147
Figure 8.9: EBSD compression axis IPF maps of high-efficiency stable region deformed at (a) 723K (450 °C) and 10^{-3} s^{-1} (strain ~ 1.5) and (b) 723K (450 °C) and 10^{-1} s^{-1} (strain ~ 1.2). Note that white boundaries denote 2° - 15° misorientation and black boundaries denote $> 15^\circ$ misorientation.	149
Figure 8.10: Cumulative misorientation profile along the line D in Figure 8.9 (b).	150
Figure 8.11: EBSD compression axis IPF maps of medium efficiency stable region deformed at 623K (350 °C) and 0.1 s^{-1} . Note that white boundaries denote 2° - 15° misorientation and black boundaries denotes $> 15^\circ$ misorientation.	151

Figure 8.12: EBSD compression axis IPF maps of an unstable region deformed at 523K (250 °C) and 10 s^{-1} (black boundaries denotes grain boundaries $> 15^\circ$ misorientation, white boundaries denotes $\{1012\}$ TTW boundaries and blue boundaries denotes $\{1011\}$ - $\{1012\}$ DTW boundaries)..... 153

List of tables

Table 2.1: List of common alloying elements in the Mg	7
Table 2.2: Details of common slip system observed in Mg alloys	9
Table 2.3: Mechanical properties of Mg-Y binary alloys under tensile loading.	30
Table 5.1: The elemental composition of as-cast material obtained from EDS data.....	79
Table 5.2: Summary of compression properties of Mg-5Y and Mg-10Y alloys.	85
Table 5.3: Effect of Y (wt. %) content on c/a ratio as determined from XRD	92
Table 6.1: Summary of tensile properties of as-rolled and annealed Mg-5Y and Mg-10Y. .	117
Table 7.1: Dislocation density using XRD at different rolling strains.	131