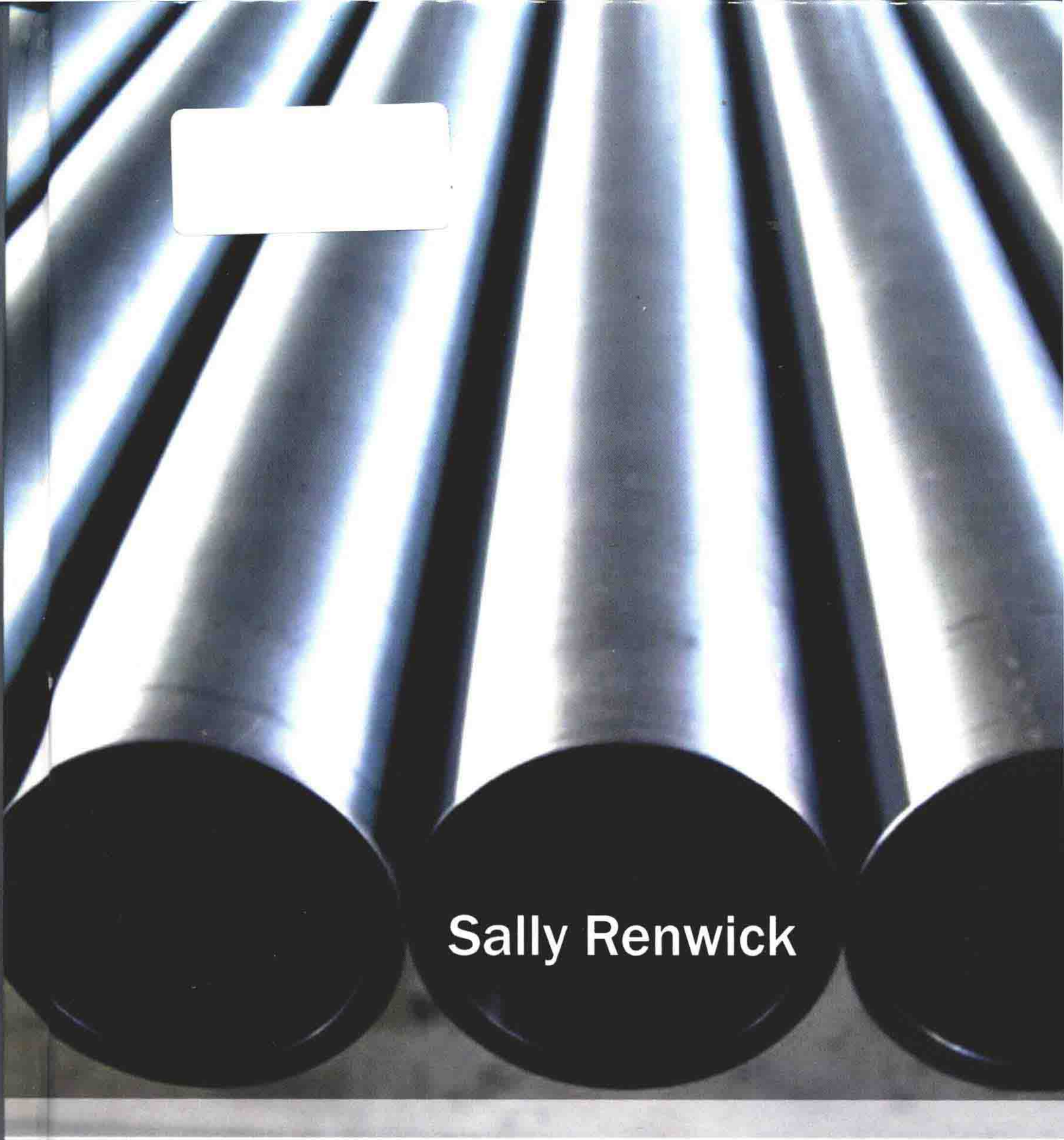

Sally Renwick

Magnesium Alloys
Concepts, Properties and Applications

Magnesium Alloys: Concepts, Properties and Applications

Edited by **Sally Renwick**

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Preface

This book aims to highlight the current researches and provides a platform to further the scope of innovations in this area. This book is a product of the combined efforts of many researchers and scientists, after going through thorough studies and analysis from different parts of the world. The objective of this book is to provide the readers with the latest information of the field.

Magnesium alloys have been utilized extensively due to its various features; its density is low, it is malleable, easily available and one of the most machinable metals. This has led to an increase in magnesium alloys applications. A study of magnesium alloys related to technological functions and environmental requirements has been discussed in this book. Various diverse applications of magnesium alloys, for example, enhancing the malleability of some specific magnesium alloys, molding magnesium alloys, etc. have also been elucidated. This book will be helpful for readers interested in increasing their knowledge about magnesium alloys.

I would like to express my sincere thanks to the authors for their dedicated efforts in the completion of this book. I acknowledge the efforts of the publisher for providing constant support. Lastly, I would like to thank my family for their support in all academic endeavors.

Editor

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Section 1

Properties and Microstructure of Magnesium-Based Quasicrystals

Chapter 1

Mg-Based Quasicrystals

Zhifeng Wang and Weimin Zhao

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1. Introduction

Quasicrystals (QCs) are a well-defined ordered phase of solid matter with long-range quasiperiodic translational order and an orientational order [1], but no three dimensional translational periodicity [2]. In 1984, Shechtman et al [3] first reported these structures in a rapidly solidified Al–Mn alloy. It brings about a paradigm shift in solid-state physics for these atomic arrangements are forbidden for conventional crystallography [4] and have long been thought forbidden in nature. The unexpected discovery of QCs presents scientists with a new, puzzling class of materials and involves hundreds of researchers in this realm. During the beginning period for QC study, many QCs were fabricated in Al-based alloys [5]. Luo et al [6] discovered first Mg-based QCs in Mg-Zn-(Y, RE) system in 1993 which extend the alloy system of QCs.

So far, QCs in various systems have been synthesized in laboratories [2] and have also been discovered in a natural mineral [7] which comes from extraterrestrials. Many noticeable results were disclosed. The reported evidence [8] indicates that QCs can form naturally under astrophysical conditions and remain stable over cosmic timescales, giving unique insights on their existence in nature and stability. In 2011, the Nobel Prize in Chemistry was awarded to Daniel Shechtman for "the discovery of quasicrystals". Nowadays, scientists all over the world refocus these amazing materials and their promising applications.

As is well-known, QCs possess a host of unusual mechanical and physical properties [9] such as high strength, high thermal conductivity, and low friction coefficient [10]. Though they cannot be applied directly as structural materials for their innate brittleness, they can be used as good strengthening phases for some flexible matrix. Moreover, QCs have good corrosion resistance and were introduced into compounds which have been applied in some medical fields [11,12]. In this chapter, QC morphology evolution, its influence factors, QC-strengthened alloys and QC corrosion resistance are discussed. These basic researches are very useful for further development of QCs.

2. Morphologies of quasicrystals

QCs present fascinating three dimensional morphologies such as dodecahedral and icosahedral shapes (Fig.1). In different alloy systems, QC can be produced by slow-cooling method or rapidly solidified method. Mg-Zn-Y QCs possess a broad QC forming range. They can be synthesized in a common casting process [10].

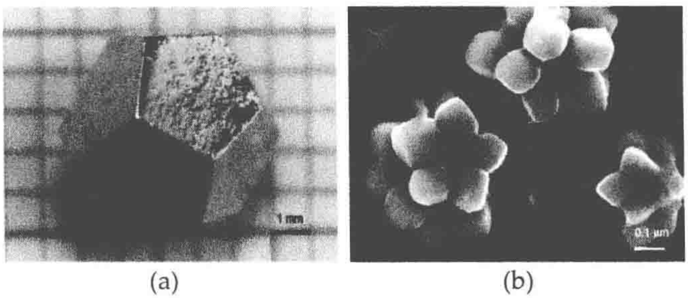


Figure 1. Fascinating quasicrystals [13] (a) Dodecahedral Zn-Mg-Ho single QC grain (b) Icosahedral Al-Mn QC flowers

2.1. Morphology evolutions of Mg-Zn-Y quasicrystals [14]

The $Mg_{72}Zn_{26.5}Y_{1.5}$ (at.%) alloys were produced by a reformed crucible electric resistance furnace (SG_2-5-10A, as shown in Fig.2), melted under the mixture of SF_6/CO_2 protective atmosphere. Stirring for 2 min by impellor at 1073K and holding for 5 min above 1053K, the melt was poured and cooled by different cooling media (as shown in Fig.3 and Table 1). The cooling curves (as shown in Fig.4) of the alloys were monitored by multichannel data acquisition cards. The results showed that, the cooling rate was sequentially decreased from cooling media 1 to 5. The SEM images of Alloy 1 ~ Alloy 5 were shown in Fig.5.

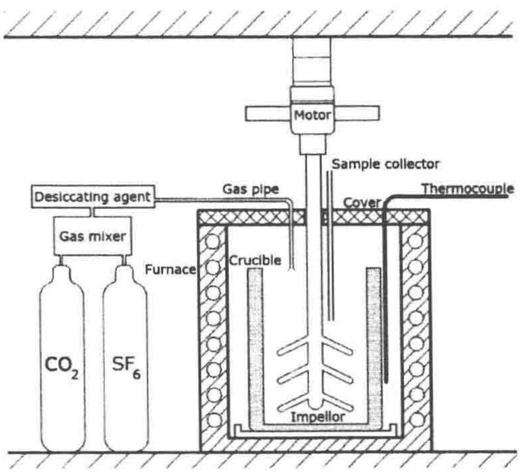


Figure 2. Schematic diagram of apparatus for making QC alloys

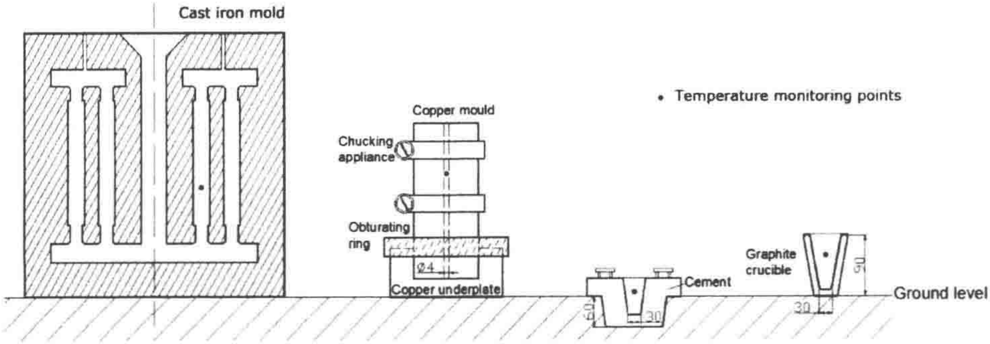


Figure 3. Schematic diagram of cooling media

Alloy no.	Cooling media
1	Be extracted by sample collector and cooled in water
2	Copper mould
3	Cast iron mould
4	Cement mould
5	Be poured into a graphite crucible and cooled in air

Table 1. Cooling media of the alloys

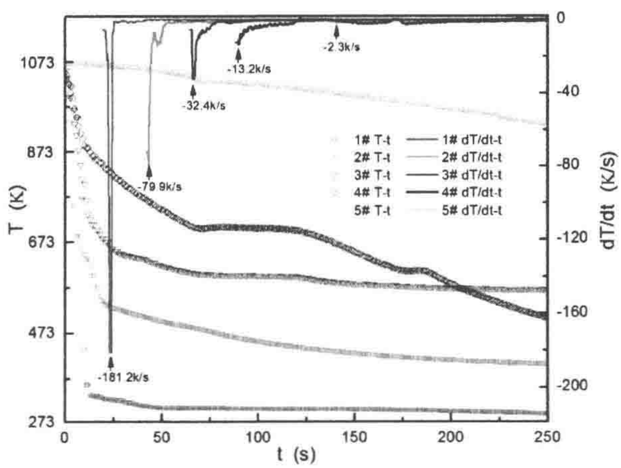


Figure 4. Cooling curves of the Alloys

The QC size gradually increased and the QC morphology changed with decreasing cooling rate. Decahedral quasicrystals (DQCs) were formed in Alloy 1 under cooling media 1, while icosahedral quasicrystals (IQCs) were formed in Alloy 2 ~ Alloy 5 under other cooling media. Moreover, the microhardness was larger for the smaller-sized QCs (Table 2). IQCs are quasiperiodic in three dimensions, while DQCs are quasiperiodic in two dimensions [2]. The DQCs formed in Alloy 1 presented flat bacilliform morphology and 10-fold symmetry characteristic. With decreasing cooling rate, the IQCs in Alloy 2 and Alloy 3 exhibited petal-like morphology under metal mould casting condition. Furthermore, the slower cooling rate induced larger IQC petals. With the further decrease of the cooling rate, the IQC petals showed nearly circular morphology. Finally, the IQCs grew up to large polygons in the slow cooling conditions.

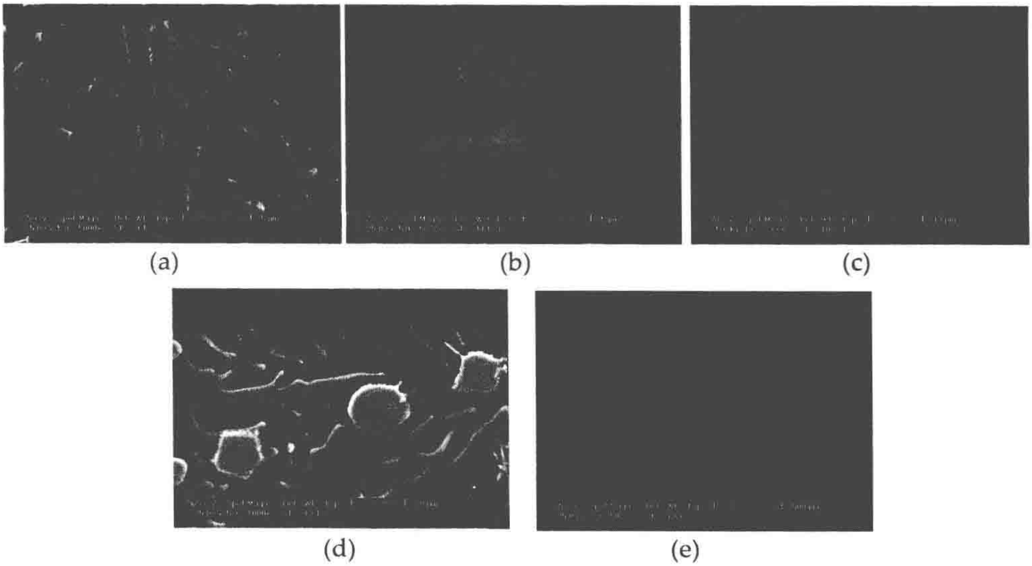


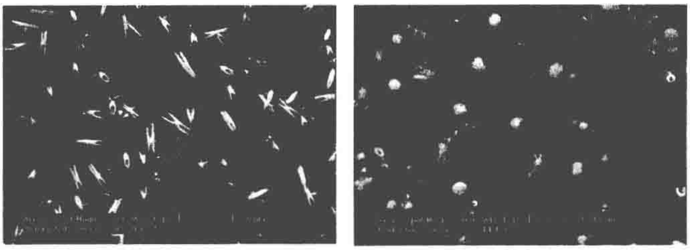
Figure 5. SEM images of Alloy 1~5 a) Alloy 1 (b) Alloy 2 (c) Alloy 3 (d) Alloy 4 (e) Alloy 5

Alloy no.	QC size / μm	QC morphology	QC microhardness / HV
1	10~12 in length	Flat X-shape	287
2	4~6	Petal-like	272
3	10~15	Petal-like	157
4	18~22	Near circular petal-like	182
5	300~400	Polygon	195

Table 2. Comparisons of the quasicrystals

In order to clarify how the IQCs transformed from morphology of Alloy 1 to Alloy 2, the $Mg_{72}Zn_{26}Y_{1.5}Cu_{0.5}$ alloys were synthesized under a water-cooled copper mold with pouring gate diameter of 2 mm and 4 mm. Such cooling rates were just between the cooling media 1 and 2. The cooling rate of water-cooled copper mold with pouring gate diameter of 2mm was faster than that of 4mm. Flat DQCs like Alloy 1, and spherical IQCs were formed respectively in Fig.6 (a) and (b), and pouring gate diameter was 2mm and 4mm correspondingly. We can see from Fig.6, a plane branch grew out in one of two-dimensional (2D) prior growth directions of the flat DQCs (marked by a red arrow in Fig.6 (a)). And then more branches grew out in three-dimensional (3D) directions (marked by a red arrow in Fig.6 (b)).

These branches increasingly became dense and agglomerate, and finally created a cluster for the primary IQC morphology.



(a) (b)

Figure 6. SEM images of $Mg_{72}Zn_{26}Y_{1.5}Cu_{0.5}$ alloys (a) Flat DQC (b) Spherical IQC

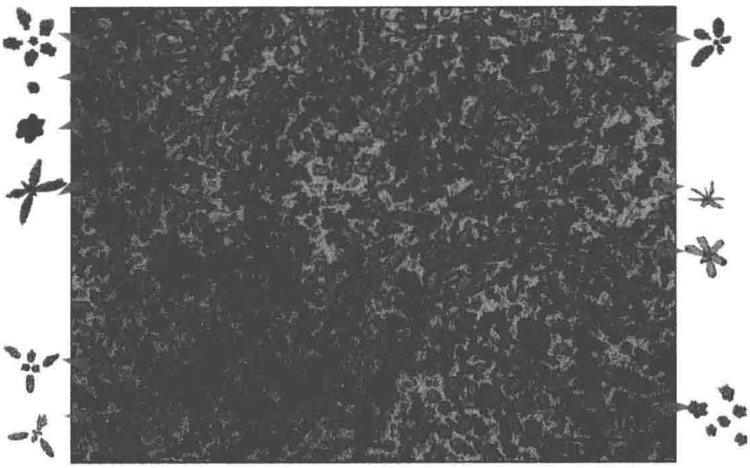


Figure 7. Optical microstructure of Alloy 3 after heat treatment at 750 K for 15 min

A heat treatment for Alloy 3 at 750 K for 15 min was prepared for studying IQC growth process between IQC morphology in Alloy 3 and in Alloy 4. It can be seen from Fig.7 that various shapes of QCs at different growth stages were formed in the heat treatment process. There were plentiful IQC nuclei in as-cast Alloy 3, but the growth was not complete due to a fast cooling process. The petals shown in Alloy 3 were the ones who had experienced the nucleation process only, but do not have enough time to grow up into the morphology in Alloy 4. During the heat treatment, the IQC nuclei continued to grow.

From the above, the IQC morphology evolution process between IQCs in Alloy 1 and Alloy 2 as well as between IQCs in Alloy 3 and Alloy 4 were revealed. A general drawing of morphology evolution of Mg-Zn-Y quasicrystal phase in growth process was shown in Fig.8. Twenty-two kinds of typical morphology of Mg-Zn-Y QC phase during cooling process were extracted from SEM and OM images.

During cooling process of Mg-Zn-Y alloys, at first a plane branch (shape 2) grew out in one of prior growth directions of the flat DQCs (shape 1). And then more branches emerged and created a cluster (shape 3), which was the primary morphology of IQCs. At the beginning of the IQC growth stage, its morphology was near spherical (shape 4). The spherical interface was not maintained with alteration of the ambience conditions. Along the prior growth directions, the spherical IQC sprouted five petals (shape 5) or six petals (shape 16). These petals subsequently grew up and became larger in length (shape 6 and shape 17), and further separated from each other (shape 8 and shape 18). The separated IQC petals grew up (shape 9) and became new independent IQCs (as shape 5). If there were still leftover Zn and Y elements in the melt, the IQC petals will continue to split and repeat the cycle from shape 5 to shape 9 until they were used up. With decrease of the cooling rate and increase of the growth time, the IQCs became maturity and grew bigger (shape 11), and finally grew into bulk polygons.

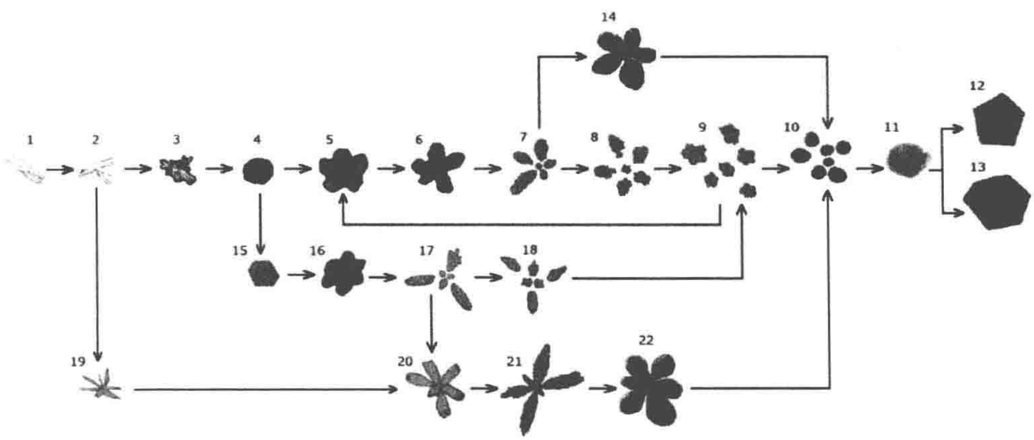


Figure 8. Schematic diagram of morphology evolution of Mg-Zn-Y quasicrystal phase in growth process

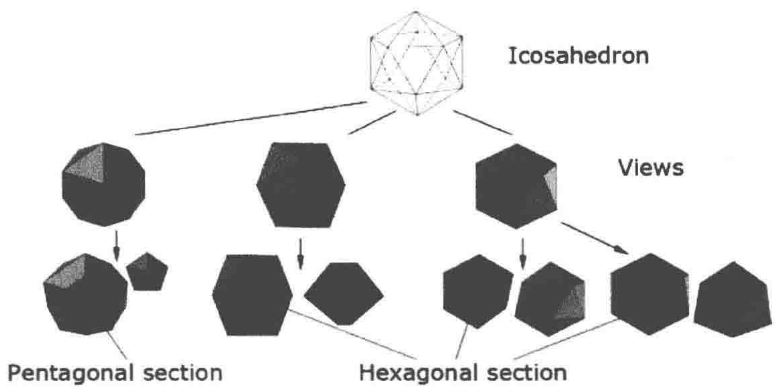


Figure 9. Section schematic diagram of icosahedrons

The reason why the final morphology of IQCs was pentagonal (shape 12) and hexagonal (shape 13) polygon can be showed in Fig.9: a mature Mg-Zn-Y quasicrystal is an icosahedron in a 3-D view; when we observe it in different directions, it show different