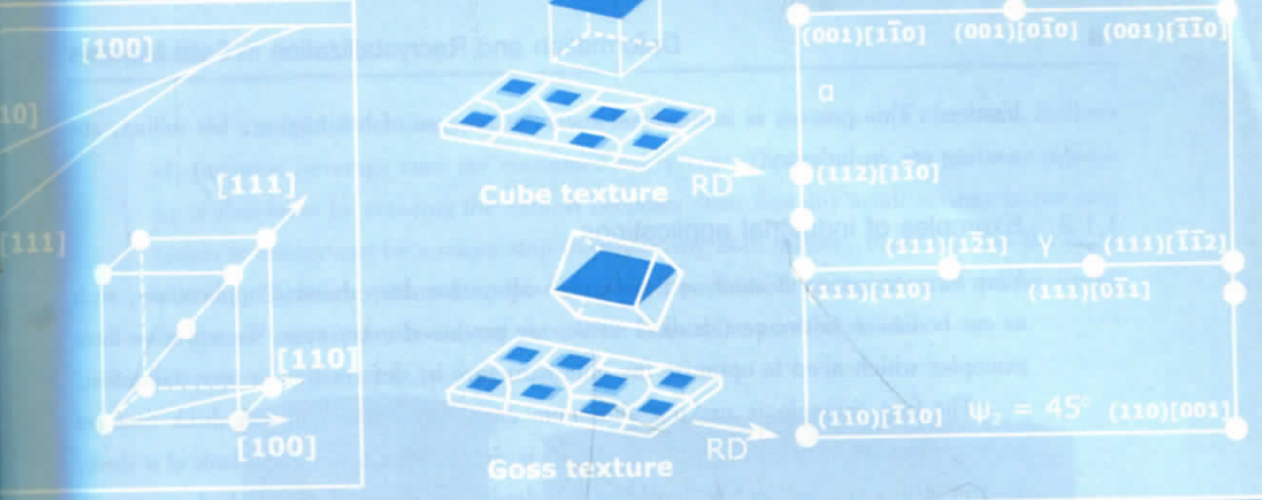


1 Introduction

1.1 Why this book

1.1.1 Deformation-recrystallization and their microstructure

The materials paradigm is represented in the form of a famous tetrahedron shown in Figure 1-1(a). The basis or core of material science involves the microstructure of materials, and their relationship to the properties and performance of a material in a given application. The major determinants of the microstructure in a material are its constituent chemical elements or composition and the way in which it has been processed into its final form, i. e. materials processing. Deformation or/and recrystallization are the main methods to tailor the microstructure in addition to phase transformation.

Deformation is a necessary step during materials processing and their applications. While materials are being processed into construction parts, deformation not only forces a material into its final shape, but also changes the internal structure (microstructure). Therefore, deformation is a method for microstructure optimization, i. e. according to the real demand to adjust processing parameters to obtain a good combination of strength and plasticity. Moreover, the processed components will be subjected to mechanical loading during its application, and suffer from certain amount of deformation before final failure. Therefore, understanding the microstructure change is also beneficial to understand the deformation process and improve their performance.

We also discuss (in terms of dislocations) why heat treating a deformed alloy makes it softer and more ductile and produces changes in its microstructure (Recrystallization). This process is indispensable in the process of hot forging, hot rolling, annealing etc. in industry.

1.1.2 Examples of industrial applications

Very large tonnages of steel and aluminum alloys for deep-drawing applications, such as car bodies or beverage (drinks) cans, are produced every year. We will show three examples which need to optimize the microstructure by deformation or recrystallization.

The first example is making aluminum cans. Most beer and soft drink cans are made of aluminum. When a cylindrical cup is drawn from a circular blank of a sheet, the rim of this cup will not be level but will depict a number of distinct high points usually called ears and the same number of low points, called troughs, as shown in Figure 1-2. This earing effect is undesirable, as it causes inhomogeneous reduction of wall thickness and it may interfere with automated deep drawing operations. Moreover, these ears will be cut off and increase the cost of final product.

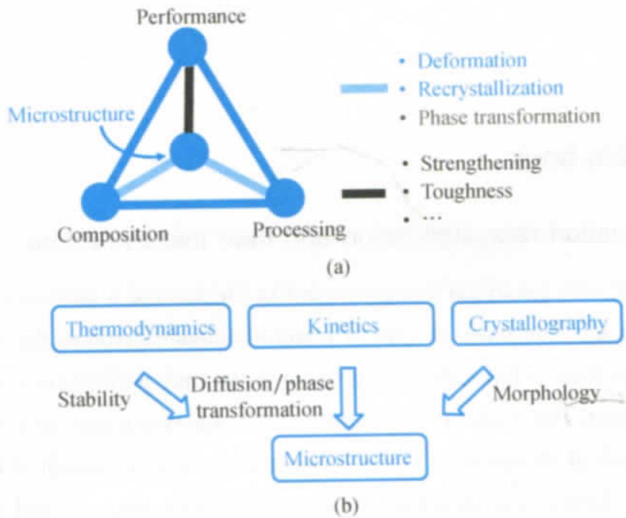
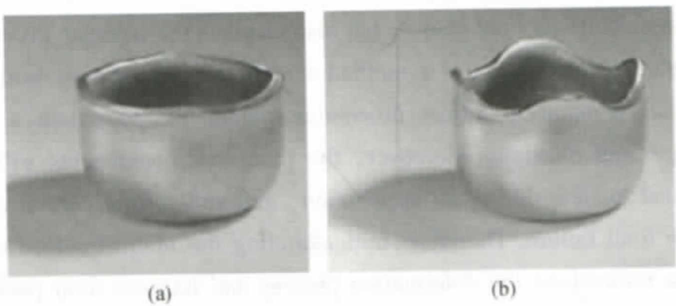


Figure 1-1 (a) The materials paradigm represented in the form of a tetrahedron, (b) Fundamental knowledge for microstructure controlling.



(a) (b)

Figure 1-2 Earing during deep drawing.

In a rough estimation, about 1g will be lost due to the ears in a can body. Billions of aluminum beverage cans are consumed every year. That is to say we can save million kg of aluminum by avoiding the ears. It becomes clear that any small savings in raw materials or energy can be a major step in conserving both money, resources and the environment. Therefore, many attempts have been performed to suppress or reduce earing by proper microstructure control as will be shown later in this book.

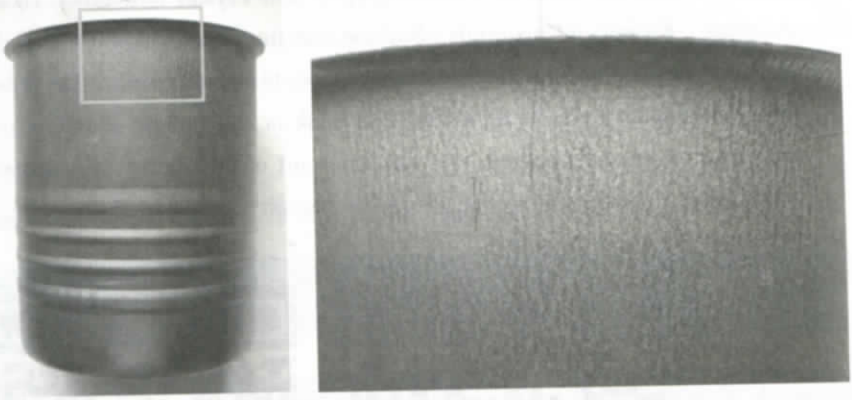


Figure 1-3 Orange-peel after drawing of steel sheet.

The second example is the production of silicon steel. It is well known that the physical/chemical property of single crystal is anisotropic due to anisotropic atomic arrangement. However, this anisotropic property will be averaged out in poly-crystalline materials with grains oriented at different directions. In poly-crystalline materials, the property can be optimized by changing the orientation of each grain during deformation/crystallization. The optimal crystallographic direction of magnetization in Fe-3%Si steels for power transformers is [001]. According to the magnetization curves of transformer steels, the [001] direction is magnetically the softest; that is, it experiences minimum magnetization losses upon remagnetization. Hence, it is necessary to control the microstructure during processing of Fe-3%Si steels so as to reach the best magnetic property along [001] direction in this poly-crystalline material.

The final example is the defects on the surface known as "Orange-peel" shown in Figure 1-3, which is due to inhomogeneous deformation. This kind of surface defect will affect the quality of the materials.

The above three examples show us that the knowledge on deformation and recrystallization is crucial to understand and control the microstructure in materials during various industrial processes.

Despite the importance of deformation or/and recrystallization in industrial application, the textbook on deformation and recrystallization for undergraduate student is unavailable. Therefore, it is a purpose of this book to fill the gap and also to include current/cutting-in-edge understandings of deformation and recrystallization.

1.2 Relationship between this course and other major courses

The course of "Fundamentals of Materials Science" is the most important course for the students majoring in materials science and engineering. Since this course contains more than one hundred lecture hours and it is quiet hard to teach in English, it is divided into several courses such as Crystallography and crystal structure, Thermodynamics of materials, Kinetics of materials, Surface and interfaces in solid materials, Deformation and recrystallization in solid materials, Phase transformation of materials etc. Nevertheless, one should keep in mind that this book or this course of Deformation and recrystallization is an independent, yet also one part of the course "Fundamentals of Materials Science". Basic knowledge of crystallography and crystal structure, interfaces are necessary for present course.

(a) (b)

Figure 1-4 Link to the homepage of the course. (a) Link to current course (only for students in USTB). (b) Link to the Chinese course of "Fundamentals of Materials Science".

1.3 Contents in this book

This book covers the aspects of deformation structure, recovery, recrystallization and grain growth, and characterization methods of microstructure. Correspondingly, it will be divided into three parts, namely, plastic deformation, recrystallization and analytical techniques. The deformation at high temperature will be dealt with in a separate chapter because both processes (deformation/crystallization) can occur concurrently, which is much complicated.

1.4 How to learn

Before learning this book, a basic knowledge on crystal structures, dislocations, interfaces etc. is needed. Readers are encouraged to check them by doing the exercises at the end of this chapter.

The laws of thermodynamics, kinetics and crystallography govern a material's microstructure as shown in Figure 1-1(b). As a result, these three aspects are all covered for both deformation and recrystallization.

In addition, there are two websites for further references, including reading materials, and teaching videos in Chinese. Readers can access the web sites by scanning the QR codes in Figure 1-4. At the beginning of each chapter, learning objectives are listed to be checked during learning process. At the end of each chapter, there are exercises to practice after finishing each chapter.

1.5 Exercises

The exercises below are to help review the basic knowledge needed for this book.

Exercise 1.1 Plot fcc, bcc and hcp structures, and list all variants (crystallographic equivalent solution) of the closest packed planes and directions. ■

Exercise 1.2 Plot [001] standard stereographic projection for cubic crystals, denote the pole indices less than 2, and plot their corresponding big circles. ■

Exercise 1.3 Describe the defects are in crystalline materials, and how they affect the material properties. ■

Exercise 1.4 What are full dislocation, partial dislocation and stacking fault? ■

Exercise 1.5 Plot the energetic stable configurations for two parallel interacted dislocations with the same or opposite Burgers vectors. ■

Exercise 1.6 Supposing the bonding energy between the nearest neighbor atoms is ε, calculate the surface energy of (111), (011) and (001) planes in fcc and bcc structures by using nearest-neighbor broken-bond model, and compare the surface energies with the atomic package in the planes. ■

Exercise 1.7 Write down the rotation matrix in cubic crystals with rotation axis around [100], [010] and [001] with a rotation angle of θ, respectively. ■

Exercise 1.8 Discuss the possible grain boundary structures varying with the misorientation angles and their relationship to grain boundary energy. ■

Exercise 1.9 Discuss the factors affecting the migration of grain boundaries. ■