

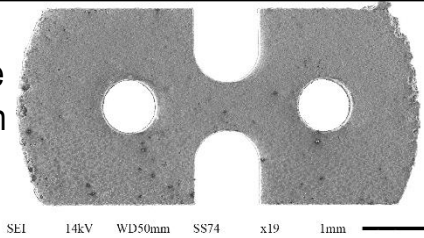
論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Microstructure evaluation of single crystal pure iron in static recrystallization
著者(和文)	LuoZichao
Author(English)	Zichao Luo
出典(和文)	学位:博士(学術), 学位授与機関:東京工業大学, 報告番号:甲第11208号, 授与年月日:2019年3月26日, 学位の種別:課程博士, 審査員:吉野 雅彦,大竹 尚登,阪口 基己,山崎 敬久,山本 貴富喜
Citation(English)	Degree:Doctor (Academic), Conferring organization: Tokyo Institute of Technology, Report number:甲第11208号, Conferred date:2019/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

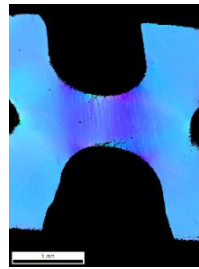
Study on deformed texture

Microstructural evolution during tensile deforming studied with CP-FEM and EBSD

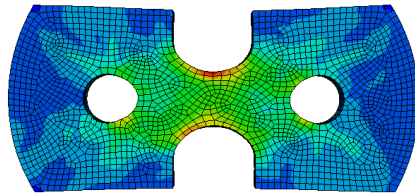
Tensile test on single crystal iron specimen



Derive texture information by EBSD



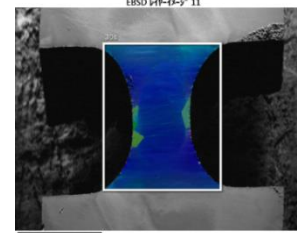
Crystal plasticity finite element simulation with measured initial microstructure



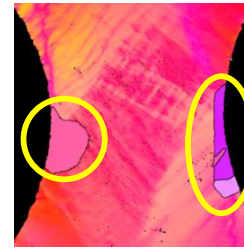
Study on nucleation site

Prediction of nucleation sites with different parameters

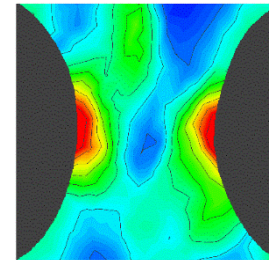
In-situ EBSD observation on static recrystallization



Determine approximate nucleation sites



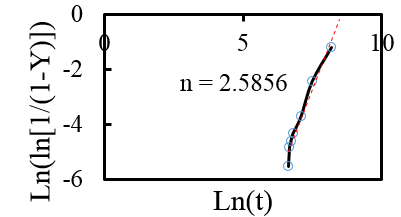
Prediction of nucleation positions with calculated KAM



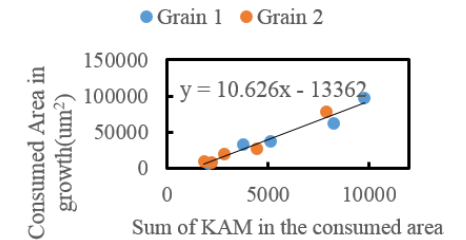
Study on grain growth

Grain boundary migration observation with in-situ EBSD and modelling the grain growth

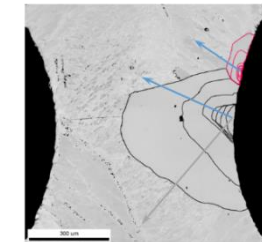
Modelling overall kinetics



Single grain growth vs KAM



Modelling boundary migration velocity



Summary of main conclusions:

- CP-FEM model which can reproduce the deformed characteristics has been developed;
- KAM value calculated from CP-FEM delivers an effective mesoscale representation of local deformation and can qualitatively predict nucleation positions.
- Cellular automaton model was built to simulate grain growth based on EBSD data. Relative roles of curvature related energy and stored deformation energy were studied: the former takes effect in regularizing grain boundary shape to reduce boundary energy; and the later would generate protrusions toward highly deformed matrix and is the main driving force of boundary migration.

Outline of thesis

The following list describes the outline of this thesis:

CHAPTER 1: Introduction

In this chapter, the relationship between microstructure of metal materials and their physical properties is introduced. Two methods to modify microstructure of metals, namely alloying and TMCP are covered. The merits of TMCP over alloying are underlined and current problems regarding to the application of TMCP are briefly reviewed. Study on the evolution of microstructure in TMCP can be decomposed into three subtopics: deformed microstructure, nucleation and grain growth.

CHAPTER 2: Literature review

This chapter follows the reasoning in Chapter 1 and is devoted into literature review on the aforementioned three topics: deformed microstructure, nucleation and grain growth. Both experimental approaches and numerical studies are covered.

CHAPTER 3 – Experimental and numerical study of deformed microstructure

This chapter describes the methodology used for the current study, including details about experimental setting and CP-FEM simulation setting. The former subsection covers specimen fabrication, tensile deforming and in-situ EBSD observation. The latter is mainly about fundamental theories of CP-FEM, boundary conditions of current model and optimization method for the derivation of hardening parameters. After these two subsections, the direct comparison between experiments and simulations is made to evaluate the model.

CHAPTER 4 – Prediction of nucleation sites

In this chapter, first the approximate nucleation sites were derived from in-situ observations. Then the comparison between experimentally derived KAM and calculated KAM is made. Based on the derived quantities, nucleation rules from literature are tested.

CHAPTER 5 – Grain growth in recrystallization

This chapter mainly describe observations and modelling on grain growth during recrystallization. Starting from in-situ observation results, grain growth kinetics are discussed and qualitative discussions are made on both single grain kinetics and the change of grain boundary morphology during grain growth. Grain growth is modeled with cellular automaton based on orientation information derived from EBSD observation.

CHAPTER 6: Conclusions

This final chapter of this thesis describes the concluding summary of the research project.

Contents

Chapter 1 Introduction	1
1.1 Research background	1
1.1.1 Microstructure of metal and material properties	1
1.1.2 Thermomechanical control process for the production of advanced high strength steels	3
1.1.2.1 Introduction to thermomechanical control process.....	3
1.1.2.2 Review on structural control with TMCP	5
1.1.2.3 Summary	9
1.2 Research objective	10
1.3 Research approach	10
1.4 Organization of the thesis.....	11
Chapter 2 Literature review	14
2.1 Texture evolution during plastic deforming	14
2.2 Studies on nucleation sites and nucleation criterion	17
2.2.1 Nucleation mechanism	17
2.2.2 Modelling nucleation in static recrystallization	22
2.3 Observations and modelling of grain growth	25
2.3.1 Experimental observations of grain growth.....	25
2.3.2 Numerical studies of grain growth.....	32
2.4 Summary	36
2.4.1 Summary of studies on texture evolution during plastic deforming	36
2.4.2 Summary of studies on nucleation	37
2.4.3 Summary of studies on grain growth	37
2.4.4 Drawbacks of previous research works on texture evolution and features of the current study	38
Chapter 3 Experimental and numerical study of deformed microstructure	41
3.1 Tensile test on single crystal pure iron specimen	41
3.1.1 Specimen design, fabrication and tensile deforming	41
3.2 CP-FEM simulation of texture evolution during tensile deforming	48
3.2.1 Fundamentals of Crystal plasticity theory	48
3.2.2 CP-FEM model of tensile deforming	53
3.2.3 Identifying model parameters	57
3.3 Comparison between experimentally measured and simulated deformation characteristics	61

3.3.1 Overall deformation	62
3.3.2 Load-stroke curves	62
3.3.3 Inverse pole figures	63
3.4 Summary	64
Chapter 4 Study on nucleation sites	66
4.1 Experimental observations on texture evolution during static recrystallization	66
4.1.1 Comparison between microstructure characterization with ex-situ and in-situ observations	66
4.1.2 Experimental setting of in-situ EBSD observation	72
4.1.3 Recorded texture evolution	74
4.1.4 Approximation of nucleation sites	80
4.2 Prediction of nucleation sites in deformed single crystal iron specimens	82
4.2.1 Stored deformation energy and nucleation sites	82
4.2.2 Kernel average misorientation and nucleation sites	83
4.3 Summary	90
Chapter 5 Grain growth in static recrystallization of single crystal iron specimens	92
5.1 Grain growth kinetics in static recrystallization	92
5.1.1 Recrystallization fraction over annealing time	92
5.1.2 Individual grain growth over annealing time	94
5.2 Modelling grain boundary migration velocity	103
5.2.1 Previous models on boundary migration velocity	103
5.2.2 Characterizing grain boundary migration velocity	104
5.2.3 Modelling grain boundary migration velocity	105
5.2.3.1 Driving force of boundary migration	105
5.2.3.2 Grain boundary migration rate model	107
5.2.3.3 Comparison with experiment data	109
5.3 Grain growth simulation with cellular automata	112
5.3.1 Introduction to cellular automata model for the simulation of grain growth	112
5.3.2 Mathematical expression of boundary migration velocity with CA	114
5.3.2.1 Linearization of velocity equation	114
5.3.2.2 Decomposing into deterministic and probability part	115
5.3.2.3 Fitting into grids	115
5.3.2.4 Normalizing sweeping frequency	116
5.3.3 Implementation of 2D CA	117
5.3.3.1 Select cells to be updated	117

5.3.3.2	Driving force of grain boundary migration	118
5.3.3.3	Validation on benchmark	119
5.3.4	Simulation of grain growth and comparison with experiment results	121
5.4	Summary	128
Chapter 6	Conclusions	131