Ain Shams University
Faculty of Education
Physics Department

Plastic Behavior Due to Ge Precipitation in Al-based Alloys

THESIS

Submitted for the Degree of Master of Philosophy for the Teacher's Preparation in Science (Physics)

By

Jacklein Anwar Fawzy Riad
B. Sc. and Ed. 2007,
Gen. Diploma (Physics) 2008,
Spec. Diploma (Physics) 2009.

To

Physics Department
Faculty of Education
Ain Shams University

2013

Approval Sheet

Title : ***Plastic Behavior Due to Ge Precipitation in Al-based Alloys***

Candidate: Jacklein Anwar Fawzy Riad

Degree : Degree of Master of Philosophy for Teacher's Preparation in Science (Physics)

Board of Advisors

Approved by **Signature**

1. Dr. Mourad Helmy Nagy Beshai
Assistant Professor, Physics Department, Faculty of Education,
Ain Shams University.

2. Dr. George Helmy Deaf
Assistant Professor, Physics Department, Faculty of Education,
Ain Shams University.

3. Dr. Nihad Daoud Habib
Lecturer, Physics Department, Faculty of Education,
Ain Shams University.

Date of presentation 24 / 6 / 2013

Post graduate studies:
Stamp: / / Date of approval: / /

Approval of Faculty Council: / /2013

Approval of University Council: / / 2013

Ain Shams University
Faculty of Education
Physics Department

Thesis Title:

Plastic Behavior Due to Ge Precipitation in Al-based Alloys

Researcher Name: Jacklein Anwar Fawzy Riad

Submitted to:

Physics Department, Faculty of Education, Ain Shams University

Supervised by:

1. **Dr. Mourad Helmy Nagy Beshai**
2. **Dr. George Helmy Deaf**
3. **Dr. Nihad Daoud Habib**

Acknowledgement

Acknowledgement

I wish to express my deep gratitude to *Prof. Dr. Mostafa Hussein,* Head of Physics Department, Faculty of Education, Ain Shams University for his assistance and encouragement.

The author wishes to express her sincere appreciation for *Prof. Dr. Gamal Saad Awadalla,* Physics Department, Faculty of Education, Ain Shams University for his assistance and encouragement during this work.

The author wishes to express her sincere appreciation for *Asst. Prof. Dr. George Helmy Deaf,* Physics Department, Faculty of Education, Ain Shams University for suggesting this work, for his supervision and advice during the course of this work.

I wish also to express my deep gratitude for *Asst. Prof. Dr. Mourad Helmy Beshai*, Physics Department, Faculty of Education, Ain Shams University, for his valuable help, guidance and support, continuous encouragement and supervision throughout this work.

I would like to thank *Dr. Nihad Daoud Habib,* Physics Department, Faculty of Education, Ain Shams University, for her help, support, advice, fruitful discussions and her persistent interest.

I would like to express my deep thanks to all members of Solid State Physics, Faculty of Education, Ain Shams University for their support during this work.

Contents

Contents

		Page
	List of Figures……..……..	a
	List of Tables……..……..……..…..	g
	List of Equations ……..…..……..…….	h
	Abstract……...	i
	Summary……...…….	j
	Acceptance Letters……..	

CHAPTER I

Introduction

1.1.	Lattice Imperfections in Crystalline Solids …...	1
	Point Defects …….	1
	Edge Dislocation ……...	2
	Surface/Planar Defects ……..	3
	Volume Defects …….	4
1.2.	Interactions Between Point Defects ……..	5
1.3.	Elastic Properties of Dislocations …….	6
1.4.	Dislocation Motion ……	6
	The Glide Motion ……..	7
	The Climb Motion……..	7
1.5.	Dislocation Interactions …….	8
1.6.	Multiplication of Dislocations …….....	9
1.7.	Work-Hardening of Metals and Alloys……..	10
	Elastic Deformation……	10
	Plastic Deformation……	10
1.8.	Mechanisms of Work-Hardening ……..	11
	Strain-Hardening……	11

		Page
	Solid Solution Strengthening…….	12
	Grain Boundary Hardening……	13
	Grain Size Effect……	13
	Anneal Hardening……..	13
	Precipitation or Dispersion Strengthening…….	14
1.9.	Nucleation and Growth of Precipitates……..	18
1.10.	Grain Boundary Sliding…….	19
1.11.	Superplastic Deformation …….…….	21
1.12.	Stress-Strain Characteristics……..…….	22
1.13.	Mechanical Properties of Metals and Alloys….	27
	Modulus of Elasticity…….	27
	Yield Strength……	28
	Ultimate Tensile Strength……...	28
	Percent Elongation…….	29
1.14.	Factors Affecting the Stress-Strain Curve …….	30
	Effect of Strain Rate ……..	30
	Effect of Temperature…….....	31
	Effect of Grain Size……	32
1.15.	Aluminum-Germanium Alloys……..	34
1.16.	Al-Ge Phase Diagram ……...…….	36
1.17.	Previous Review ……...……	38
	Formation of Pure Ge Precipitate Morphologies….	38
	Superplastic Behavior of Al-Ge Alloy……...	43
	Plastic Deformation on the Precipitation Al-Ge Alloy……...	47
1.18.	Scope and Outline of the Present Work…….	51

CHAPTER II

Experimental Techniques and Devices

Page

2.1.	Samples Preparation……..	53
2.2.	Heat Treatments ……..…….....…....	54
2.3.	The Components of the Mechanical System…..	56
2.3.1.	Tensile-Testing Machine…….…….....	56
(a)	The Force Sensor ……...…….……...…	58
(b)	The Rotary Motion Sensor …….……...…	58
(c)	The Science Workshop 500 Interface …….….....	58
(d)	The Software (Data Studio Software)…..……...	58
2.4.	Measurement Technique…….….....	60
2.5.	X-ray Diffraction (XRD)…….....	62
2.6.	Transmission Electron Microscope (TEM)……	63

CHAPTER III

Experimental Results and Observations Below 423 K

3.1.	Tensile Properties and Microstructure Changes of Al–4wt%Ge and Al–4wt%Ge–0.1%Zr Alloys Aged From 323 K to 423 K ……...……	67
3.2.	Effect of Aging Times and/or Temperatures on the Stress-Strain Parameters in Both Alloys …	73
3.3.	TEM investigations……..…….…….	80
3.3.1.	Effect of Aging Time……...…..	81
3.3.2.	Effect of Aging Temperature ……	85
3.3.3.	Effect of Zirconium Addition ……..……..	88

CHAPTER IV *Page*

Experimental Results and Observations Above 423 K

4.1.	Tensile Properties of Al – 4 wt. % Ge and Al – 4 wt. % Ge – 0.1 % Zr Alloys Aged From 448 K to 573 K……..	93
4.2.	Effect of Both Aging Time and Aging Temperature on the Strength Parameters of Both Alloys (A & B)……..	94
4.3.	TEM investigations……	106
4.3.1.	Effect of Aging Time ……	106
4.3.2.	Effect of Aging Temperature ……...…….	110
4.3.3.	Effect of Zr Addition……..	113
	Conclusions ……...	116
	References …….……	118
	Arabic Summary ……..……	

List of Figures

List of Figures

Figure	*Caption*	*Page*
Fig. 1.1 :	Schematic aging curve.	17
Fig. 1.2 :	A typical stress-strain curve.	24
Fig. 1.3 :	Tensile stress-strain curves for metals.	27
Fig. 1.4 :	Al-Ge phase diagram.	37
Fig. 2.1 :	The temperature uniformity along the axis of the furnace.	54
Fig. 2.2 :	The calibration curve for the annealing furnace.	55
Fig. 2.3 :	Schematic diagram of the mechanical system.	57
Fig. 2.4 :	The force sensor.	59
Fig. 2.5 :	The rotary motion sensor.	59
Fig. 2.6 :	The science workshop 500 interface.	60
Fig. 2.7 :	Stress-strain relationship as obtained by the data studio graph.	61
Fig. 2.8 :	An automatic electrolytic thinning machine (Tenupole-3).	64
Fig. 2.9 :	Electron microscope type of a JEOL-100s.	65

Figure	*Caption*	*Page*
Fig. 3.1 :	The stress-strain curves for both alloys (A & B) aged at: 323, 348 and 373 K, for different aging times as indicated.	69,70
Fig. 3.2 :	(Stress) ^{2} versus strain $(\sigma^2 - \varepsilon)$ for specimens of both alloys (A & B) aged at different aging temperatures.	71,72
Fig. 3.3 :	Effect of aging time on $(\sigma_{y0.2})$ for specimens of both alloys (A & B) aged at different aging temperatures.	74
Fig. 3.4 :	Effect of aging time on $(\sigma_{y0.2})$ for specimens of both alloys (A & B) aged at T_a = 423 K. $(\sigma_{y0.2})$ for alloy B are slightly higher than those for alloy A.	74
Fig. 3.5 :	Effect of aging time on the parabolic work hardening coefficient χ_p for specimens of both alloys (A & B) aged at different aging temperatures.	76
Fig. 3.6 :	Effect of aging time on ultimate stress (σ_u), for specimens of both alloys (A & B) aged at different aging temperatures.	76

Figure	*Caption*	*Page*
Fig. 3.7 :	Effect of aging time on stress to fracture **(σ_f)** for specimens of both alloys (A & B) aged at different aging temperatures.	78
Fig. 3.8 :	Effect of aging time on Young's modulus **(Y)** for specimens of both alloys (A & B) aged at different aging temperatures.	78
Fig. 3.9 :	Effect of aging time on the strain to fracture percent or the ductility **(ε_f %)** for specimens of both alloys (A & B) aged at different aging temperatures.	80
Fig. 3.10:	TEM micrographs of specimens of both alloys (A & B) aged at 423 K for 1 hour (a & c) and 6 hour (b & d) respectively, showing the coalescence of Ge particles as a function of aging time. And, (d) the formation of coffee bean contrast which marked by arrows.	82
Fig. 3.11:	The XRD record for both alloys A&B.	84

Figure	*Caption*	*Page*
Fig. 3.12:	TEM micrographs of specimens of both alloys (A & B) aged for 1 hr at 323 K (a & b) and 423 K (c & d) showing irregular and spherical particles of Ge precipitates developed at sub-grain boundaries and inside grains as a function of aging temperatures.	87
Fig. 3.13:	Effect of aging time on the mechanical parameters **(σ_u, σ_f, χ_p** and **Y)** for specimens of both alloys (A & B) aged at T_a = 423 K.	89
Fig. 3.14:	A montage of TEM micrographs of specimens of both alloys (A & B) aged for 1 hr at 423 K showing: (a) dense irregular Ge precipitates at sub-grain boundaries in alloy A (b) moderate irregular Ge precipitates at sub-grain boundaries in alloy B.	91
Fig. 4.1 :	The stress-strain curves for both alloys (A & B) aged at: 448, 473 and 498 K for different aging times as indicated.	95,96