EFFECT OF HEAT TREATMENT ON THE MICROSTRUCTURES AND HARDNESS OF Ti-48Al-xCr ALLOYS

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This thesis is dedicate to

My mother Fatimah binti Abu Kassim

And

My father Mohamed Jamil bin Abdul Samad

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ABSTRACT

Microstructural developement during continuous cooling (0.245^oC/min to 500^oC/min) from the α-Ti phase region and subsequent annealing treatment, 1450^oC (15minutes) ⟶ 1250^oC (1 hour) has been investigated using Ti-48Al, Ti-48Al-2Cr, Ti-48Al-4Cr and Ti-48Al-8Cr (at. %) alloys. In the Ti-48Al alloys and Ti-48Al-2Cr, nearly fully lamellar transform fully lamellar with the lamellar grain size and lamellar spacing decrease as the cooling rates increases. At slowest cooling rates, a small amount of Widmanstatten-lamellar structure observed appears to be intermediate between the lamellar structure. Meanwhile, addition of chromium up to 4%, at any cooling rates the lamellar grain size remain unchanged. But the formation of β phase is increases at fastest cooling rate (oil quenched). This is due to the precipitation of the β phase at grain boundaries during heat treatment and insufficient time to dissolve to α and γ phase due to fast cooling. Slowest cooling rates (furnace cooled) all β phase completely dissolved as the following transformation $\beta \longrightarrow \alpha + \gamma \longrightarrow \alpha_2 + \gamma$. The study revealed at 8% of Chromium slowest and fastest cooling rates shows large portion of β phase at precipitated at grain boundaries but at intermediate cooling rates the β phases seem disappeared or dissolved. Microhardness analysis shows that several factors significantly increase the hardness value of Ti-48Al alloys which is the evolution of α_2-volume fraction, high cooling rates and smallest lamellar spacing.

ABSTRAK

Pembentukan mikrostruktur semasa penyejukan berterusan (0.245°C/min to 500°C/min) daripada α-Ti fasa dan diikuti dengan pembaikan penyepuhlindapan 1450°C (15minit) → 1250°C (1 jam) telah dikaji dengan menggunakan Ti-48Al, Ti-48Al-2Cr, Ti-48Al-4Cr and Ti-48Al-8Cr (at. %) aloi. Bagi Ti-48Al and Ti-48Al-2Cr aloi, berhampiran sepenuhnya lamella mengubah kepada sepenuhnya lamella dengan saiz bijian lamela dan penurunan jarak lamela sebagai kenaikan kadar pendinginan. Pada kadar paling perlahan penyejukan, sejumlah kecil struktur Widmanstatten-lamela diperhatikan muncul untuk menjadi perantaraan di antara struktur lamela. Sementara itu, kromium sehingga 4%, di mana-mana kadar pendinginan saiz bijian lamela kekal tidak berubah. Tetapi pembentukan fasa β meningkat pada kadar terpantas penyejukan (minyak dipadamkan). Ini adalah disebabkan oleh pemendakan fasa β di sempadan bijian semasa rawatan haba dan masa yang tidak mencukupi untuk membubarkan α dan γ fasa disebabkan oleh penyejukan pantas. Penyejukan kadar paling perlahan (relau disejukkan) semua fasa β sepenuhnya dibubarkan sebagai β transformasi berikut $\beta \rightarrow \alpha + \gamma \rightarrow \alpha_2 + \gamma$. Kajian ini mendedahkan pada 8% Kromium paling perlahan dan terpantas kadar pendinginan menunjukkan sebahagian besar fasa β di dicetuskan di sempadan bijian tetapi pada kadar penyejukan perantaraan fasa β seolah-olah hilang atau dibubarkan. Analisis Microhardness menunjukkan bahawa beberapa faktor meningkatkan nilai kekerasan aloi Ti-48Al yang evolusi pecahan α_2-isipadu, kadar penyejukan yang tinggi dan terkecil jarak lamela.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE PAGE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vii
	TABLE OF CONTENTS	viii
	LIST OF TABLES	xii
	LIST OF FIGURES	xiv
	LIST OF ABBREVIATIONS	xx
1	**INTRODUCTION**	
	1.1 Introduction	1
	1.2 Objectives	3
	1.3 Statement of Research Problems	4
	1.4 Scope of Study	4
2	**LITERATURE REVIEW**	
	2.1 Introduction	5
	2.2 Titanium Alloys	6
	2.3 Titanium Aluminides	7

2.3.1 Intermetallic Compound 9
2.4 Near Gamma Titanium Aluminides 10
2.4.1 Equaixed Microstructures 12
2.4.2 Lamellar Microstructures 12
2.4.3 Duplex Microstructures 13
2.5 Two Phase Near Gamma Titanium Aluminides 14
2.5.1 Crystal Structure 14
2.5.2 Microstructures 15
2.5.2.1 Microstructures Features 17
2.5.3 Mechanical Properties 18
2.6 Ternary Gamma Titanium Aluminides 20
2.6.1 Effect Addition of Chromium on Microstructure of Ti-Al alloys 21
2.6.2 Effect Addition of Chromium on Mechanical Properties of Ti-Al alloys 24
2.7 Application of Titanium Aluminides 24
2.7.1 Aerospace Applications 25
2.7.2 Automotive Applications 27

3 HEAT TREATMENT

3.1 Introduction 29
3.2 Transformation from α field 30
3.2.1 Massive Transformation 30
3.2.2 Widmanstatten Formation 31
3.2.3 Lamellar Formation 32
3.3 Transformation of γ Titanium Aluminides 34
3.3.1 Discontinous Coarsening 36
3.4 Effects of Heat Treatment on Microstructures and Mechanical Properties 36
3.5 Effects of Different Cooling Rate on Microstructures 41

4 RESEARCH METHODOLOGY

4.1 Introduction 44
4.2 Materials 45
4.3 Sample Preparations 47
4.4 Heat Treatnent Processes 48
4.5 Material Characterization
    4.5.1 Energy Dispersive X-Ray Analysis (EDX) 49
    4.5.2 X-Ray Diffraction (XRD) 50
    4.5.3 Optical Image Analyzer 51
    4.5.4 Scanning Electron Microscope (SEM) 52
    4.5.5 Characterization of Microstructural Features 53
4.6 Room Temperature Mechanical Characterization 53
    4.6.1 Hadness 53

5 RESULTS AND DISCUSSIONS

5.1 Introduction 55
5.2 Microstructural Characterization of As-Received Materials 55
    5.2.1 Chemical Composition of Ti-48Al Alloys 55
    5.2.2 Microstructure of Ti-48Al Alloys 56
    5.2.3 X-Ray Diffraction Analysis of As-received Samples 59
    5.2.4 Energy Dispersive X-Ray Analysis of As-Received Samples 61
    5.2.5 Hardness Property of As-Received Ti-48Al Alloys 62
5.3 Effects of Chromium on Heat Treated Ti-48Al-xCr Alloys 64

5.3.1 Microstructure Characterization of Heat Treated Ti-48%Al Alloys 64
  5.3.1.1 Hardness Property of Heat Treated Ti-48%Al Alloys 69
5.3.2 Microstructure Characterization of Heat Treated Ti-48%Al-2%Cr Alloys 70
  5.3.2.1 Hardness Property of Heat Treated Ti-48%Al-2%Cr Alloys 75
5.3.3 Microstructure Characterization of Heat Treated Ti-48%Al-4%Cr Alloys 76
  5.3.3.1 Hardness Property of Heat Treated Ti-48%Al-4%Cr Alloys 80
5.3.4 Microstructure Characterization of Heat Treated Ti-48%Al-8%Cr Alloys 81
  5.3.4.1 Hardness Property of Heat Treated Ti-48%Al-8%Cr Alloys 85
5.4 Effects of Cooling Rates on Heat Treated Ti-48Al -xCr Alloys 86
5.4.1 Oil Quenched 86
5.4.2 Air Cooled 88
5.4.3 Furnace Cooled 89

6 CONCLUSION 92

REFERENCES 95
APPENDICES 97

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Comparison of typical properties with conventional Ti-Alloys, superalloys, α_2-Ti$_3$Al and γ-TiAl based Intermetallics	8
2.2	Classification of near gamma titanium aluminides	15
2.3	Chemical composition of lamellar structure, γ phase and β phase in Ti-48Al alloys	23 23
2.4	Results of lamellar grains size and lamellar spacing measurements	23
3.1	Microstructures and average diameter at different cooling rate after heat treated at 1200°C for Ti-48 and Ti-45at.%Al	42
4.1	Chemical Composition of as-received and as-cast γ -TiAl samples	45
4.2	Parameters for X-Ray Diffraction (XRD) measurement	50
5.1	Results of EDX analysis	56

5.2 Chemical composition of lamellar structure, γ phase and β phase in Ti-48Al alloys 62

5.3 Average hardness of Ti-48Alloys 63

5.4 Results of lamellar grain size and lamellar spacing measurements 67

5.5 Measurement of average grain size and lamellar spacing of Ti-48%Al-2%Cr 73

5.6 Chemical composition each phase (γ and α_2) of heat treated Ti-48%Al-2%Cr 74

5.7 Measurement of average grain size of Ti-48%Al-4%Cr 78

5.8 Compositions of $\alpha_2 + \gamma$ lamellae, fine γ and β phase in Ti-48%Al-4%Cr 79

5.9 Compositions of $\alpha_2 + \gamma$ lamellae, fine γ and β phase in Ti-48%Al-8%Cr 83

83

5.10 Measurement of average lamellar grain size and lamellar spacing of Ti-48%Al-8%Cr

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Proposed Titanium-Aluminium Phase Diagram	10
2.2	Central portion on Ti-Al binary phase diagram. Shaded area indicates composition range that is the basis for two-phase gamma titanium aluminides	11
2.3	Illustration of the apparent microstructures in γ-TiAl; a) equiaxed b) duplex and c) lamellar	12
2.4	Crystal Structure of γ-TiAl	14
2.5	Scanning electron (back scattered electron mode) micrograph of γ-TiAl	16
2.6	Optical micrograph of γ-TiAl	18
2.7	Phase equilibria of Ti-Al-Cr ternary system at 1200^{0}C and 1000^{0}C	22
2.8	Low pressure turbine (LPT) rotor	25
2.9	Low pressure turbine (LPT) γ blades in the as-cast condition ready for machining	26

2.10 (a) Investment Cast γ-TiAl Diffuser (Schafrik, 2001), (b) Close-Out Beam Castings of γ-TiAl for Outlet-Nozzle of HSCT Engine (Loria, 2000), (c) Transition Dust-Beam Castings of γ-TiAl for GE90 Engines (Loria, 2000), (d) Cast I-Beam and Track ofγ-TiAl for Outlet-Nozzle of HSCT Engine (Loria, 2000). 26

2.10 (continued) (e) Advanced Engine Rada Diffuser of As-Cast γ-TiAl (Loria, 2000), (f) Triple Corrugation (Loria, 2000). 27

2.11 Cast Turbocharger Rotor using Ti-46Al-7Nb-1Cr 27

2.12 Cast γ-TiAl Exhaust Valves in Testing for High Performance Cars in US and in Europe 28

2.13 Piston Head for a Diesel Engine 28

3.1 Movement of the Shockley parts transferring from hcp to fcc 33

3.2 Binary phase diagram of Ti-Al alloys 35

3.3 Optical micrograph of a nearly lamellar microstructure 35

3.4 Schematic illustration of the cycle heat treatment route 37

3.5 Schematic illustration of the refining process occurring by discontinuous coarsening in one cycle of CHT-B 37

3.6 Effects of numbers of cycles on the average grain diameter and grain boundaries Ti-48Al-2Cr-CNb 38

3.7 Microstructure before and after rapid heat treatment a) as cast b) After 8 times R-HT 39

3.8 Optical microstructure of a) one step HT and b) two steps HT 40

3.9 Schematic diagram when the TiAl alloys heated to near α phase temperature 41

3.10 Microstructures of Ti-46Al-2Cr-2Nb after solutions treated at 1350^{o}C for 15 min and then a) water, b) organic aqueous solution NQ, c) oil queched. γ_f : feathery γ; γ_m: massive γ 43

4.1 Research Methodology 46

4.2 Schematic drawing of sample for polishing 47

4.3 Schematic drawing for heat treatment test 47

4.4 Schematic heat treatment temperature-time path used in heat treatment, T_α = Temperature transus α phase field, T_e = Eutectoid temperature, T_t =Temperature treatment. Q =Quenched, A=Air-cooled, FC= Furnace-cooled 48

4.5 Schematic Drawing of X-Ray Detector for EDX Analysis 49

4.6 X-Ray Diffractometer 50

4.7 Image Analyzer 51

4.8 Scanning Electron Microscope 52

4.9 Vickers Microhardness Tester 54

5.1 Optical micrographs of Ti48%Al alloys: (a) Ti-48%Al (b) Ti-48%Al-2%Cr 57

5.1 (continued) Optical micrographs of Ti48%Al alloys: (c) Ti-48%Al-4%Cr and d) Ti-48%Al-8%Cr 58

5.2 XRD results of Ti-48Al alloys: (a) Ti-48%Al 59

5.2 (continued) XRD results of Ti-48Al alloys: (b) Ti-48%Al-2%Cr and (c) Ti-48%Al-4%Cr and (d) Ti-48%Al-8%Cr 60

5.3 **a)** Optical Micrograph of Ti-48Al-8Cr at magnification of 50x; b) and c) EDX results to verify β phase (spot A) and γ (TiAl) phase (spot B) 61

5.4 Average hardness at room temperature as a function of Crcontents in As-received Ti-48Alloys 64

5.5 Optical Micrograph of heat treated Ti-48%Al followed by (a) Oil quenched and (b) Air cooled 66

5.5 (continued) Optical Micrograph of heat treated Ti-48%Al followed by (c) Furnace cooled 67

5.6 XRD analysis on the heat treated Ti-48%Al followed by (a) Oil quenched and (b) Air cooled 68

5.6 (continued) XRD analysis on the heat treated Ti-48%Al followed by (c) Furnace cooled 69

5.7 Microhardness at room temperature as a function of cooling rate in Ti-48%Al alloys 70

5.8 Optical Micrograph of heat treated Ti-48%Al-2%Cr followed by (a) Oil quenched; (b) Air cooled and (c) Furnace cooled 72

5.9 XRD analysis on the heat treated Ti-48%Al-2%Cr followed by (a) Furnace cooled 74

5.9 (continued) XRD analysis on the heat treated Ti-48%Al-2%Cr followed by (b) Oil quenched and (c) Air cooled 75

5.10 Average microhardness at room temperature as a function of cooling rate in Ti-48%Al-2%Cr alloys 76

5.11 Optical Micrograph of heat treated Ti-48%Al-4%Cr followed by (a) Oil quenched and (b) Air cooled 77

5.11 (continued) Optical Micrograph of heat treated Ti-48%Al-4%Cr followed by, c) Furnace cooled 78

5.12 XRD analysis on the heat treated Ti-48%Al-4%Cr followed by (a) Oil quenched and (b) Air cooled 79

5.12 (continued) XRD analysis on the heat treated Ti-48%Al-4%Cr followed by (c) Furnace cooled 80

5.13 Average microhardness at room temperature as a function of Cr contents in Ti-48%Al-4%Cr alloys 81

5.14 Optical Micrograph of heat treated Ti-48%Al-8%Cr followed by (a) Oil quenched; (b) Air cooled and (c) Furnace cooled 82

5.15 X-Ray Diffraction Analysis on heat treated Ti-48%Al-8%Cr followed by (a) Oil quenched; (b) Air cooled and (c) Furnace cooled 84

5.16 Average microhardness at room temperature as a function of Cr contents in Ti-48Al-8Cr alloys 85

5.17 Average microhardness after heat treated and as-received as a function of Cr contents in Ti-48Al alloys 87

5.18 Average microhardness after heat treated and as-received as a function of Cr contents in Ti-48Al alloys 89

5.19 Average microhardness after heat treated and as-received as a function of Cr contents in Ti-48Al alloys 91

LIST OF ABBREVIATIONS

CHT	Cycle Heat Treatment
RHT	Rapid Heat Treatment
FL	Fully Lamellar
NFL	Nearly Fully Lamellar
%	Percentage
^0C	Degree celsius
at.%	Atomic percentage
Ti_3Al	Super alpha titanium aluminide
TiAl	Gamma titanium aluminide
α_2	Super alpha/hexagonal closed packed atomic structure
γ	Gamma Phase/ tetragonal atomic structure
β	Betha phase/ cubic atomic structure
α	Alpha phase/ hexagonal atomic structure
Ti-Al	Titanium-aluminum
Ti-Al-Cr	Titanium-aluminum-chromium
HCP	Hexagonal closed packed
BCC	Body centered cubic
RT	Room temperature
ASTM	American Standard for Testing Materials
EDM	Electro discharge machine
Ti	Titanium
Cr	Chromium
SEM	Scanning Electron Microscope
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Introduction

Development and processing of high-temperature materials is the key to technological advancement in engineering areas where materials have to meet extreme requirements. Examples for such areas are the aerospace, spacecraft and the automotive industries. New structural materials have to be stronger, stiffer and lighter to withstand the extremely demanding conditions in the next generation of aircraft engines, space vehicles and automotive engines. Intermetallic γ-TiA1 based alloys exhibit numerous attractive properties which meet these demands. These properties include high melting point, low density, high specific elastic modulus, good oxidation and burn resistance, and high specific strength up to application temperatures of 700°C to 900°C. Thus, γ-TiA1 based alloys outperform advanced Ti-based alloys and have the potential to replace heavy Ni-based superalloys (Zheng *et al*., 1995; Cheng *et al*., 1999).

The most promising alloys, which is based on the Ti-48Al composition (in at.%) with ternary and quaternary additions, are characterized by the two-phase Ti_3Al + TiAL (α_2+γ) lamellar microstructure (Kim and Dimiduk, 1991). One way to obtain variety of microstructures is by the addition of β-stabilizing elements such as chromium. Most of their properties, such as tensile, creep, fatigue and fracture, are dominated by microstructures for given compositions. The properties of these alloys are quite sensitive to microstructures; near lamellar structure for ternary alloys (with 2 at.%Cr) show highest tensile strength, ductility, modulus elasticity and toughness but the presence of β phase (> 4at.%Cr) in Ti-Al based alloys deteriorates its ultimate tensile strength and ductility at room temperature as well as creep strength at high temperature with respect to the applications (Hamzah et al., 2008), whereas fully lamellar structure have poor ductility (S.C. Huang, 1991) . On the other hand, the creep resistance of the fully lamellar structures is considerably superior to that of duplex structure (S.C. Huang, 1991).

The lamellae transformation is of greatest importance because fully lamellar structures can offer good and balanced properties (D.M. Dimiduk et al., 1991). This is referred to lamellae spacing. Studies have shown that fully lamellae microstructures with very fine lamellae spacing give better mechanical properties such as creep and toughness (W.Schillinger, 2002). But extremely fine lamellae spacing come along with a very high dislocation density and internal stresses which causes detrimental to creep resistances (Schillinger., 2002). However, the present study revealed that controlled alloying element does not have significant effect on the microstructural features such as lamellae spacing and grain size. Thus, no effects on the mechanical properties. These features are usually controlled by heat treatment (M.Kanniah, 2006). Various microstructures can be obtained through different heat treatment steps by controlling several parameters (annealing temperature, holding time and cooling rate). The final microstructures can be massively transformed γ to feathery or Widmanstatten type lamellae (Lutjering et al., 2003), duplex microstructures (Hamzah et al., 2005) and discontinous or continous coarsening lamellae (Y. Zheng et al.,1996). For this reason it is necessary to understand and quantify the influence of and heat treatment on the microstructure and the corresponding mechanical properties.

Subsequent heat treatments above the α-transus are needed to develope the metastable structure, which leads to a substantial grain growth and ductility loss. One factor that controls the ductility is grain size, and generally the finer the grain size the higher the ductility (Y.W.Kim, 1992). On the other hand, heated at α_2+γ region has little effects on as-cast fully lamellae morphology. Beside that, previous studies show that the β phase amount drastically reduced when the temperature of annealing above 1250°C (α+γ region) for 168h followed by water quenching (Y.Zhen, 1996). As mentioned before, this phase is brittle at room and high temperature that limit these alloys for high temperature applications.

Thus, the aim of this study is to determine the effect of heat treatment on the microstructures and its influence on the mechanical properties, of a γ-based TiAl alloy containing Cr. Since these alloy are to be used at high temperatures it is important to characterize the microstructure of the as-received material and to observe the changes that may occur during long, high-temperature exposures comparable to those in service. It is also necessary to understand how any microstructure changes produced by the heat treatments affect the mechanical properties of the material. Therefore, designing the optimum heat treatment process by controlling severals paramaters (annealing temperature, holding time and cooling rate) to optimize its mechanical properties is necessary.

1.2 Objective of The Research

The objective of this research is to determine the effect of heat treatment on the microstructure and its influence on mechanical properties, of a γ-based TiAl alloy containing Cr.

1.3 Statement of Research Problems

How does heat treatment affects microstructure and mechanical properties of binary and ternary TiAl based alloys?

1.4 Scope of Study

The scopes of the study are as follows;

a) Microstructural characterization before and after heat treatment on Ti-Al and Ti-Al-Cr samples

b) Different heat treatments has been designed based on Ti-Al phase diagram to obtain different microstructures that lead to different mechanical property. All materials will be have similar heat treatment process.

c) Determination of mechanical property namely hardness for all heat treated samples.

d) Analysis of results to relate between microstructures obtained and hardness after heat treatment.