I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the Bachelor's degree of Mechanical Engineering (Structure and Material)

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Date : May 2009

EFFECT OF HEAT TREATMENT PROCESS OF TITANIUM FOR WATCH MANUFACTURING APPLICATION

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APRIL 2009

“I hereby the author, declare this report entitled “ EFFECT OF HEAT TREATMENT PROCESS ON TITANIUM FOR WATCH MANUFACTURING APPLICATION” is my own work except for quotation and summaries which have been state the source”

Signature : ___________________________

Author : Mohd Najmi bin Abdullah Sani

Date : 10 April 2009

To my dearest parent

Mr Abdullah Sani bin Salam and Mr Nafsiah binti Mat Wali

My sibling,

Masni binti Abdullah Sani

Mazlan bin Abdullah Sani

Mohd Fahmi bin Abdullah Sani

Thanks for all the support

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious, The Most Merciful. Firstly, an utmost gratitude to Allah S.W.T for giving me comforts, patience and opportunity in time and space to successfully complete my final year project thesis or Project Sarjana Muda (PSM).

I also like to express my gratitude to all those who have helped me in one way or another way during the planning, information gathering, writing, editing and reformatting stages of this thesis report. I am particularly indebted to my Projek Sarjana Muda (PSM) subject's supervisor, Mr Ahmad Kamal bin Mat Yamin for his guidance about the information and guideline in doing the Project Sarjana Muda (PSM) report. Millions of thanks also are giving to my supervisor, Pn. Nortazi binti Sanusi for the guidance and advice including the feedback that enabled me to improve upon producing this report. Thanks also to my fellow undergraduates, Bachelor of Structure and Material (BMCS) lectures Mr. Wan Mohd Farid b Wan Mohamad, Mrs. Rafidah binti Hassan , Mrs. Siti Hajar b. Sheikh Md. Fadzullah, and Mrs. Zakiah binti Abdul Halim for sharing their insights and opinion on thesis report writing and providing me with genuine materials in the form of internet sites and engineering books. Besides that, I would like to express my gratitude to my parents for the love and support that they have given me. Finally, I would like to thanks everyone who is willing to spend their precious time reading my thesis report.

ABSTRACT

High strength, low density, and excellent corrosion resistance are the main properties that make titanium attractive for a variety of applications. Examples include aircraft (high strength in combination with low density), aero engines (high strength, low density, and good creep resistance), biomedical devices (corrosion resistance and high strength) and components in chemical processing equipment (corrosion resistance). Titanium also has been an attraction in everyday wear accessories like watch. The advantages of titanium use in watch application are such as it is light, comfortable, hypoallergenic which is free from nickel, durable and have corrosion resistance feature. To give a better quality of titanium in watch application, heat treatment procedure is applied to it. Many methods are use in titanium heat treating. There are such as annealing, quenching, tempering, solution treating and aging and isothermal transformation. Heat treatment process generally execute is to improve the materials properties. The amount of phase present in titanium is control by heat treatment process. The phases that have in titanium are alpha, beta, alpha-beta, near-alpha and near beta. Mechanical test is then executed to prove the quality of heat treatment process in term of its parameter use. The suitable mechanical testing has been choosing for this research and they are Rockwell Hardness Test and Charpy Impact Test. For microscopic analysis Optical Microscope is use to analyze the microstructure of specimen that not undergo heat treatment and specimen that undergo heat treatment process. Data obtain from experimental and testing process will be statistically analyzed by F-Test and T-test method.

ABSTRAK

Kekuatan yang tinggi, ketumpatan yang rendah dan daya tahan karat yang sangat baik adalah ciri-ciri atau sifat-sifat utama yang menjadikan titanium satu tarikan untuk diaplikasikan di dalam pelbagai bidang. Antara bidang-bidang yang mengaplikasikan penggunaan titanium adalah seperti pembuatan pesawat udara (kombinasi kekuatan yang tinggi dan ketumpatan yang rendah), enjin kapal angkasa (kekuatan yang tinggi, ketumpatan yang rendah dan daya tahan kesotan yang baik), alatan bio-perubatan (daya tahan karat yang baik dan kekuatan yang tinggi) dan komponen alatan pemprosesan bahan kimia (daya tahan karat yang baik). Titanium juga telah menjadi satu daya tarikan dalam penggunaan dan pemakaian harian seperti jam. Kelebihan penggunaan titanium dan titanium aloi dalam aplikasi jam adalah ianya ringan, selesa dipakai, hipoalergik iaitu bebas dari nikel, tahan lama dan mempunyai ciri-ciri daya tahan karat. Untuk memberikan mutu yang baik ke atas titanium di dalam penghasilan jam, proses rawatan haba di aplikasikan. Terdapat banyak cara dalam rawatan haba titanium. Antaranya adalah menyepuh lindap, melindap, pembajaan, rawatan larutan dan penuaan dan transformasi isoterma. Proses rawatan haba pada umumnya dilakukan untuk mempertingkatkan sifat-sifat bahan. Di dalam perawatan haba titanium, jumlah fasa alpha, beta, alpha-beta, hampir-alpha and hampir-beta akan dikawal. Setelah perwatan haba selesai, ujian mekanikal dilakukan untuk menunjukkan parameter yang digunakan adalah bagus. Ujian mekanikal seperti Ujian Kekerasan Rockwell dan Ujian Hentaman Charpy turut dijalankan di dalam kajian ini. Mikrostruktur titanium sebelum dan selepas rawatan haba akan di analisa menggunakan Mikroskop Optik. Data yang dikeluarkan daripada semua kaedah yang digunakan akan dianalisa secara statistik meggunakan kaedah Ujian F dan T.

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LIST OF ABBREVIATIONS AND SYMBOLS

Al	=	Aluminium
ASM	=	American Society for Metals
ASTM	=	American Standard of Testing and Material
BHN	=	Brinell Hardness Number
BCC	=	Body centered cubic
B120VCA	=	Titanium alloys sheet
CP	=	Commercially pure
C	=	Carbon
CNC	=	Computer Numerical Control
Cr	=	Chromium
CRT	=	Cathode Ray Tube
E	=	Modulus of Elasticity
F	=	Load
Fe	=	Ferum
FE	=	Field Emission
$FeTiO^3$	=	Ilminite
g/cm^3	=	Gram per cubic centimeter

GPa	=	Giga Pascal
H	=	Hydrogen
HCP	=	Hexagonal closed-packed
HDH	=	Hydrogenation or dehydrogenation
HF	=	Hydrofluoric
HNO_3	=	Acid nitric
HRB	=	Rockwell Hardness B scale
HRC	=	Rockwell Hardness C scale
HV	=	Hardness Vickers Number
I	=	Iron
J	=	Joules
kV	=	Kilovolts
kg	=	Kilograms
kg-f	=	Kilograms-Force
mm	=	Millimeters
Mpa	=	Mega Pascal
m^2	=	Square millimeters
N	=	Nitrogen
Ni	=	Nickel
O^2	=	Oxygen
ppm	=	Parts per million
SEM	=	Scanning Electron Microscopy

Si	=	Silicon
$\mathbf{S_1}$	=	Standard deviation
$\mathbf{S_1}^2$	=	Variance
Ti	=	Titanium
TiO^2	=	Titanium oxide or rutile
Ti-3Al-8V-6Cr-4Mo-4Zr	=	Titanium 3% Aluminium 8% Vanadium 6% Chromium 4% Molybdenum 4% Zirconium
Ti-6Al-4V	=	Titanium 6% Aluminium 4% Vanadium
Ti-6Al-2Sn-4Zr-2Mo+Si	=	Titanium 6% Aluminium 2% Sn 4% Zirconium 2% Molybdenum + Silicon
Ti-6V-2Sn-2Zr-Cr-2Mo+Si	=	Titanium 6% Vanadium 2% Sn 2% Zirconium 1% Chromium 2% Molybdenum + Silicon
Ti-8Al-1Mo-1V	=	Titanium 8% Aluminium 1% Molybdenum 1% Vanadium
Ti-10V-2Fe-3Al	=	Titanium 10% Vanadium 2% Ferum 3% Aluminium
Ti-15-3	=	Titanium alloys
α	=	Alpha
ß	=	Beta
α-β	=	Alpha-beta
°C	=	Degree Celsius
°F	=	Degree Fahrenheit
$\overline{X}_1$	=	Mean

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Titanium metal was first discovered by the English chemist William Gregor in 1971 in the black magnetic sand ilmenite. The name of the titanium is referring to the titans of Greek mythology which is mean a symbol of power and strength. Titanium is the fourth most abundant metal in the Earth's crust after aluminium, iron and magnesium. The characteristics of titanium that make it is so attractive to industrial application is such as titanium has low density and high strength, good corrosion and erosion resistance to any medium including the sea water and chlorine, good oxidation resistance and have moderate strength at high temperature. Other characteristic that make it different from other light metals is its physical metallurgy which is complex and interesting. Titanium is an allotropic as an iron and its produces much more similarities in heat treatment compared to steels. Moreover, the presence of alloying elements give special characteristic in which, it can stabilize the low temperature phase, *alpha* or high temperature phase, *beta*. Like steels, titanium and its alloy are characterized by their stable room temperature phases (F. Vander Voort, George**,** *Materials Characterization & Testing: Microstructure of Titanium and Its Alloys*, 2006 September 14).

In any manufacturing industries and application including watch manufacturing, they have their own specification and criteria on the selection of titanium grade for their production. Titanium is divide into two application of industrial usage which is corrosion-resistant service and strength-efficient structures. Both applications characteristic are being used in selecting the suitable and exact grade of titanium for different type of manufacturing field. Corrosion resistant service is normally use lower-strength unalloyed titanium and fabricated into tanks, heat exchangers, or reactor vessels for chemical processing or power generation plants. Where as for the strength-efficient structures is use higher-strength titanium alloys. This grade of titanium usually applied in gas turbines, aircraft structures, drilling equipments and submerges components manufacturing field. Table 1.1 below are the several commercial and semi commercial grades for unalloyed and titanium alloys (ASM International, *The Materials Information Society*, 2000).

	Tensile strength (min)		0.2% yield strength (min)		Impurity limits, wt% (max)					Nominal composition, wt%				
Designation	**MPa**	**ksi**	**MPa**	**ksi**	**N**	**C**	**H**	**Fe**	**O**	**Al**	**Sn**	**Zr**	**Mo**	**Others**
Unalloyed grades														
ASTM grade 1	240	35	170	25	0.03	0.08	0.015	0.20	0.18	…	…	…	…	…
ASTM grade 2	340	50	280	40	0.03	0.08	0.015	0.30	0.25	…	…	…	…	…
ASTM grade 3	450	65	380	55	0.05	0.08	0.015	0.30	0.35	…	…	…	…	…
ASTM grade 4	550	80	480	70	0.05	0.08	0.015	0.50	0.40	…	…	…	…	…
ASTM grade 7	340	50	280	40	0.03	0.08	0.015	0.30	0.25	…	…	…	…	0.2Pd
ASTM grade 11	240	35	170	25	0.03	0.08	0.015	0.20	0.18	…	…	…	…	0.2Pd
α and near-α alloys														
Ti-0.3Mo-0.8Ni	480	70	380	55	0.03	0.10	0.015	0.30	0.25	…	…	…	0.3	0.8Ni
Ti-5Al-2.5Sn	790	115	760	110	0.05	0.08	0.02	0.50	0.20	5	2.5	…	…	…
Ti-5Al-2.5Sn-ELI	690	100	620	90	0.07	0.08	0.0125	0.25	0.12	5	2.5	…	…	…
Ti-8Al-1Mo-1V	900	130	830	120	0.05	0.08	0.015	0.30	0.12	8	…	…	1	1V
Ti-6Al-2Sn-4Zr-2Mo	900	130	830	120	0.05	0.05	0.0125	0.25	0.15	6	2	4	2	0.08Si
Ti-6Al-2Nb-1Ta-0.8Mo	790	115	690	100	0.02	0.03	0.0125	0.12	0.10	6	…	…	1	2Nb, 1Ta
Ti-2.25Al-11Sn-5Zr-1Mo	1000	145	900	130	0.04	0.04	0.008	0.12	0.17	2.25	11	5	1	0.2Si
Ti-5.8Al-4Sn-3.5Zr-0.7Nb-0.5Mo-0.35Si	1030	149	910	132	0.03	0.08	0.006	0.05	0.15	5.8	4	3.5	0.5	0.7Nb, 0.35Si
α-β alloys														
Ti-6Al-4V(a)	900	130	830	120	0.05	0.10	0.0125	0.30	0.20	6	…	…	…	4V
Ti-6Al-4V-ELI(a)	830	120	760	110	0.05	0.08	0.0125	0.25	0.13	6	…	…	…	4V
Ti-6Al-6V-2Sn(a)	1030	150	970	140	0.04	0.05	0.015	1.0	0.20	6	2	…	…	0.75Cu, 6V
Ti-8Mn(a)	860	125	760	110	0.05	0.08	0.015	0.50	0.20	…	…	…	…	8.0Mn
Ti-7Al-4Mo(a)	1030	150	970	140	0.05	0.10	0.013	0.30	0.20	7.0	…	…	4.0	…
Ti-6Al-2Sn-4Zr-6Mo(b)	1170	170	1100	160	0.04	0.04	0.0125	0.15	0.15	6	2	4	6	…
Ti-5Al-2Sn-2Zr-4Mo-4Cr(b)(c)	1125	163	1055	153	0.04	0.05	0.0125	0.30	0.13	5	2	2	4	4Cr
Ti-6Al-2Sn-2Zr-2Mo-2Cr(c)	1030	150	970	140	0.03	0.05	0.0125	0.25	0.14	5.7	2	2	2	2Cr, 0.25Si
Ti-3Al-2.5V(d)	620	90	520	75	0.015	0.05	0.015	0.30	0.12	3	…	…	…	2.5V
Ti-4Al-4Mo-2Sn-0.5Si	1100	160	960	139	(e)	0.02	0.0125	0.20	(e)	4	2	…	4	0.5Si
β alloys														
Ti-10V-2Fe-3Al(a)(c)	1170	170	1100	160	0.05	0.05	0.015	2.5	0.16	3	…	…	…	10V
Ti-13V-11Cr-3Al(b)	1170	170	1100	160	0.05	0.05	0.025	0.35	0.17	3	…	…	…	11.0Cr, 13.0V
Ti-8Mo-8V-2Fe-3Al(b)(c)	1170	170	1100	160	0.03	0.05	0.015	2.5	0.17	3	…	…	8.0	8.0V
Ti-3Al-8V-6Cr-4Mo-4Zr(a)(c)	900	130	830	120	0.03	0.05	0.20	0.25	0.12	3	…	4	4	6Cr, 8V
Ti-11.5Mo-6Zr-4.5Sn(a)	690	100	620	90	0.05	0.10	0.020	0.35	0.18	…	4.5	6.0	11.5	…
Ti-15V-3Cr-3Al-3Sn	1000(b)	145(b)	965(b)	140(b)	0.05	0.05	0.015	0.25	0.13	3	3	…	…	15V, 3Cr
	1241(f)	180(f)	1172(f)	170(f)										
Ti-15Mo-3Al-2.7Nb-0.2Si	862	125	793	115	0.05	0.05	0.015	0.25	0.13	3	…	…	15	2.7Nb, 0.2Si

(a) Mechanical properties given for the annealed condition; may be solution treated and aged to increase strength. (b) Mechanical properties given for the solution-treated-and-aged condition; alloy not normally applied in annealed condition. (c) Semicommercial alloy; mechanical properties and composition limits subject to negotiation with suppliers. (d) Primarily a tubing alloy; may be cold drawn to increase strength. (e) Combined $O_2 + 2N_2 = 0.27\%$. (f) Also solution treated and aged using an alternative aging temperature (480 °C, or 900 °F)

Table 1.1: Commercial and semi commercial grades and alloys of titanium

Heat treatment is a procedure of heating and cooling a material without melting. Typical objectives of heat treatments are hardening, strengthening, softening, improved formability, improved machinability, stress relief and improved dimensional stability of the materials. It also determined the microstructure of small crystals called "grains" or crystallites. The orientation of the grain structure will determined how effective its mechanical properties. The better grain orientation, the better its mechanical properties. The suitable choosing of the parameter during heat treatment process like temperature and time is important to get a better result. Followed by the heat treatment process, several testing is needed to prove the effectiveness of heat treatment parameter that is being used. The testing includes hardness test, impact test and microstructure verifying and analyzing. This is due to the specification needed in watch manufacturing application to maintain the watch quality. The testing will be perform on two condition of the specimen which is specimen undergo heat treatment process and specimen that not undergo heat treatment process. From the result obtained, statistical analysis will be done to provide the analysis of the titanium characteristic that suitable to be used in watch manufacturing application.

1.2 Objective

The objective of this research is to study the effect of heat treatment process of Titanium for watch manufacturing application.

1.3 Scopes

The focus of this technical research is to do a literature study of titanium, heat treatment process of titanium, titanium microscopic structure and its availability to use for watch manufacturing application. This research also will carry out the methodology of heat treatment process of titanium and the testing that perform on it. Data such as laboratory equipment, procedures, parameter use, condition and catalyst will be included in this research. The mechanical testing that will cover in this research is hardness test and impact test. The data obtain from the testing will be compared between specimen that not undergo heat treatment process and specimen undergo heat treatment process. The comparison result is use to analyze its mechanical properties. This research will also concentrate the comparison of the data obtain from all mechanical testing. The heat treatment process that applied in this research can also be used for student of Mechanical Engineering application.

1.4 Problem Statement

Watch manufacturing is one of the manufacturing fields that widely operate in Europe. This manufacturing field also includes Asia in its territory. One of the most famous watch makers is the Swatch Group. Nowadays, titanium is widely use for watch part manufacturing process, for example is the watch model from TISSOT brands, which are T-Touch Titanium and T-Touch Polished Titanium. The problem occur for material of titanium use in this model is its have defect like a small dotted and its surface finish is not smooth. This problem will cause failure when water resistant testing is executed. Other problem during the manufacturing process is that the quantity of tools use in machining process is issuing too many in one week period of production time. The tool is either broken or its total life is short. Too much total issuing will increase the cost of production process. All of the problem might come from heat treatment process, several testing procedure and drawing process of titanium production.

CHAPTER 2

LITERATURE REVIEW

Literature review is the collective of data or information from reading, references and also information from the experts relating to the projects which will be review in this chapter. From here, we will understand the purpose of the project and how we are going to achieve the result. So it is important to review all the information to make sure it will be useful beneficial for this project.

2.1 Titanium

Titanium is present in the earth's crust at a level of about 0.6% and is therefore the fourth most abundant structural metal after aluminum, iron, and magnesium. The most important mineral sources are ilmenite ($FeTiO^3$) and rutile (TiO^2) (Lutjering, G., Williams, J.C., Titanium 2nd Edition, Sub chapter 1.2, pg. 2, 2007).

High strength, low density, and excellent corrosion resistance are the main properties that make titanium attractive for a variety of applications. The examples include aircraft which have high strength in combination with low density. Aero-engines are another application that takes the advantage of titanium. The high strength, low density and good creep resistance up to about 550°C that have in titanium attract