MECHANICAL PROPERTIES OF INTERMETALLIC COMPOUNDS FOR AUTOMOTIVE APPLICATIONS

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering

by

KHAIRUL FIRDAUS BIN ZAIFUL HAKIM

B051410209

950322105067

FACULTY OF MANUFACTURING ENGINEERING

2018

DECLARATION

I hereby, declare that this thesis entitled “Mechanical Properties of Intermetallic Compounds for Automotive Applications” is the result of my own research except as cited in the references.

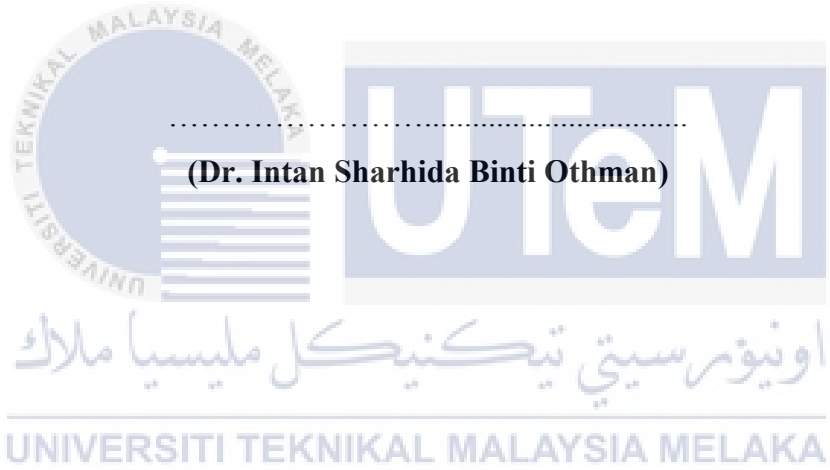
Signature : …….

Name : KHAIRUL FIRDAUS BIN ZAIFUL HAKIM

Date : 28 June 2018

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Materials) (Hons.).
The members of the supervisory committee are as follow:



…….....

(Dr. Intan Sharhida Binti Othman)

…….....

(Professor Dr. T. Joseph Sahaya Anand)

ABSTRAK

Kebocoran angin mikro dari tayar adalah fenomena yang tidak terkawal. Keadaan ini boleh membawa kepada kemalangan jalan raya. Oleh itu, tayar tanpa udara dicadangkan untuk menyelesaikan masalah ini. Tayar tanpa udara menerima lebih banyak tekanan berbanding tayar biasa disebabkan ianya tidak mempunyai sokongan udara berbanding tayar biasa. Oleh itu, bahan di pusat tayar tanpa udara perlu ditingkatkan untuk menyokong struktur tayar tanpa udara. Oleh kerana tayar tanpa udara mendapat tekanan yang lebih tinggi, bahan yang lebih baik perlu dicadangkan untuk meningkatkan prestasi tayar. Oleh itu, bahan gabungan metalik pancalogam Ni_3Al dipilih untuk digunakan sebagai bahan di pusat tayar tanpa udara. Ciri-ciri menarik pancalogam Ni_3Al seperti ketumpatan rendah, rintangan hakisan yang tinggi, digabungkan dengan keupayaan untuk mengekalkan kekuatan dan kekakuan pada suhu tinggi menyebabkan pemilihan bahan ini. Sampel pancalogam Ni_3Al disediakan di empat keadaan rawatan haba yang berbeza dalam kajian ini. Objektif utama penyelidikan ini adalah untuk mendapatkan sifat-sifat mekanikal seperti kekuatan tegangan dan kekerasan yang diuji dengan menggunakan alat ujian tarikan (UTM) dan ujian kekerasan mikro Vickers. Dengan menggunakan pembelauan sinar X (XRD), struktur kristal pancalogam Ni_3Al telah disahkan sebagai FCC. Struktur dendrit dan mendakan dapat dilihat pada pancalogam Ni_3Al dengan menggunakan mikroskop optik (OM) dan pengimbas elektron halus (SEM). Kuantiti dendrit dan mendakan menurun dengan suhu rawatan haba yang lebih tinggi. Kekerasan pancalogam Ni_3Al meningkat dengan suhu rawatan haba. Keputusan ujian tegangan menunjukkan bahawa kekuatan tegangan muktamad, modulus keanjalan dan peratusan tarikan berkurangan apabila peningkatan suhu rawatan haba. Sifat kimia pancalogam Ni_3Al ditentukan menggunakan kaedah Penentuluaran Tafel dan ianya terbukti bahawa bahan ini sangat baik menghalang hakisan. Kesimpulannya, pancalogam Ni_3Al merangkumi kebanyakan kualiti asas untuk bahan yang dicadangkan sebagai bahan alternatif untuk pusat roda dalam aplikasi tayar tanpa udara.

ABSTRACT

Micro leakage air leak out from the tyre is a phenomenon that is out of control. This situation can lead to harm such as road accidents. Therefore, airless tyre is proposed to solve the problem. Airless tyre receives more pressure than the normal tyre since it does not have cushion effect from air compared to normal tyre. Since airless tyre obtained a higher pressure than normal tyre, better material at the wheel hub of airless tyre need to be proposed to improve the tyre‟s performance. Hence, intermetallic material of Ni_3Al alloy was chosen to be used as the material at the wheel hub of airless tyre. Attractive properties of Ni_3Al alloy such as low density, high corrosion resistance, combined with their ability to retain strength and stiffness at elevated temperatures lead to its selection. In this research, the samples of Ni_3Al alloy were prepared at four different heat treatment conditions. The main objectives of this research were to obtain the mechanical properties such as tensile strength and hardness which was tested using Universal Testing Machine (UTM) and Vickers microhardness tester. By using X-Ray Diffraction (XRD), the crystal structure of Ni_3Al alloy was confirmed as FCC. The dendrites structure and precipitates was observed on Ni_3Al alloy by using optical microscope (OM) and scanning electron microscope (SEM). The quantities of dendrites and precipitates decrease with higher heat treatment temperature. The hardness of Ni_3Al alloy increased with the heat treatment temperature. The tensile test result shows that the ultimate tensile strength, modulus of elasticity and strain percentage decrease as heat treatment temperature increases. The chemical properties of Ni_3Al alloy were determined by using Tafel Extrapolation method and it is proved that this material is excellent against corrosion. It can be conclude that Ni_3Al alloy enfolds most of the basic quality for a material to be suggested as alternative material for wheel hub in airless tyre application.

DEDICATION

Only

My beloved father, Zaiful Hakim Bin Amat

My appreciated mother, Rosnita Binti Rasli

My adored sister, Anis and Ainin

For giving moral support, money, cooperation, encouragement and also understanding

Thank You So Much

ACKNOWLEDGEMENT

Alhamdulillah, thanks to Allah for the flourish blessing given, to complete this final year project successfully. My deepest appreciation is to my supervisor and co-supervisor, Dr. Intan Sharhida Binti Othman and Professor Dr. T. Joseph Sahaya Anand who gave me endless support, and guidance to make up this research up to the standard and complete in a good manner. They have been a very supportive to ensure that I could understand every single detail in this project. My gratitude is also extended to my parents and family who giving endless moral support. Last but not least my appreciation is to all my colleagues and friends. Even busy with their own individual task and commitment, they never feel hectic to give their help to me to finish up this research. Not to forget to those who directly or indirectly involved in giving me the opportunity to learn and complete this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Al	-	Aluminum
Al-Mg	-	Aluminum Magnesium
ASTM	-	American Standard of Testing and Measurement
AWJ	-	Abrasive Water Jet Cutting Machine
BCC	-	Body centered cubic
BIW	-	Body in White
BMW	-	Bravia Motor Work
FCC	-	Face centered cubic
HF	-	Hydrofluoric Acid
HV	-	Vicker"s hardness unit
Mg	-	Magnesium
NaCl	-	Sodium Chloride
Ni-Al	-	Nickel Aluminum
Ni	-	Nickel
NHT	-	None heat-treated
SEM	-	Scanning Electron Microscope
SiC	-	Silicon carbide
UTM	-	Universal Testing machine
UTS	-	Ultimate tensile strength
XRD	-	X-Ray Diffractometer

LIST OF SYMBOLS

°C	-	Degree Celsius
%	-	Percentage
Θ	-	Angle between diffraction patterns
λ	-	Wavelength of the X-ray
d	-	Interplanar spacing between the planes
X	-	Magnification
s	-	Second
A	-	Expose area
ρ	-	Density
~	-	Approximately
Å	-	Angstrom
K	-	Constant value
i_{corr}	-	Corrosion density
I_{corr}	-	Total anode current
GPa	-	Gigapascal
MPa	-	Megapascal
cm	-	Centimeter
mm	-	Millimeter
Nm	-	Nanometer
g	-	Gram
kg	-	Kilogram
kgf	-	Kilogram-force
N/mm^2	-	Newton per millimeter square
kN	-	Kilo newton
Tm	-	Melting temperature
E	-	Young‟s modulus
Ew	-	Equivalent weight
CR	-	Corrosion rate

CHAPTER 1
INTRODUCTION

This chapter describes the introduction of mechanical properties of intermetallic compounds for automotive applications. In this chapter, background of study, problem statement, objectives, scope, and the significant/important of study are discussed.

1.1 Background of Study

Global warming threatens our health, national security and other fundamental human needs. Some effects of global warming is increment in temperatures, rising oceans level, and flash flood. This air contamination carries weighty risks for human wellbeing and the surroundings. Transportation donated significant number of the carbon dioxide in the air. Fuel-proficient cars utilize less gas to travel the same distance as they have less efficient counterparts. Light weight vehicle is one of the best strategies that can be used to enhance the efficiency of vehicle.

There are two main types of metal that being used in automotive industry which is steel and aluminum. Luxurious car nowadays are utilized aluminum as the material of choice because of small in density not like the standard range automotive industry that utilized steel as their main material. Steel also inhibit corrosion problem that makes the major drawback in using it as structural of body material of vehicles. Steel will undergo rusting or corrosion difficulty after being used for an extended period of time. In 1997, Amirudin and Thierry stated that the presence of ferrous substance will triggered corrosion issue in steel.

Throughout the recent decade the total number of aluminum used in traveler cars has multiplied, and based on the new ideas growth will keep on following this pattern in the coming years. The main advantage of aluminum compared to steel are it is lighter and non-ferrous metal which means it does not undergo rusting process (Andrews *et al*., 2006). Aluminum alloys can compromise outstanding corrosion resistance with decent strength and low density compared with steel. Aluminum, when being utilized in automotive applications, spares significantly more energy and ozone depleting substance emissions over lifetime of the item. It was accounted for that 1 kg of aluminum in a car lessens carbon dioxide pollutions by 19 kg amid its entire life-cycle. Moreover, 5%-7% petroleum savings can be acknowledged for each 10% weight diminishment by substituting aluminum for denser steel over proper plan (EAA, 2012).

In this research, the main objective is to find the most suitable materials to be used in the central hub of airless tyre. Airless tyre is the results of enormous progress in science, technology, and manufacturing process. This tyre is made to solve the issue tyre failure such as puncture or blowout (Dixon, 2003). The only problem that researcher face now is as the airless tyre does not involve application of air, thus the central hub of the airless tyre need to withstand larger load than the normal tyre. New materials need to be introduced to be used as the central hub that has greater mechanical properties than the existing materials.

A compound of two metals that has a different chemical formula is the definition intermetallic. In addition, this material has established huge interest for throughout the previous ten years in material science and innovation regarding its application at high temperature and new materials are required to be produced on the fundamental of intermetallic. Transition metal silicide, iron, titanium aluminides and nickel are the examples of general intermetallic characterization. Intermetallic compounds reach the properties of ordered crystal lattice when the atoms are connected by weak metallic bonds that can be partly ionic or covalent. In 1996, Deevi and Sikka stated that the reason why intermetallic compounds experienced properties of excellent strength at elevated temperatures is because of the ability of this material to hold their order up to its melting point. (Deevi and Sikka, 1996).

Generally, intermetallic of aluminides base such as NiAl, Ni_3Al and Ni_3Al_5 will have an excellent corrosion resistance. Excellent mechanical properties and good corrosion resistance of nickel has led this material to be one of the most used material in high temperature and structural application for the last decade. Kalpajikan (2001) showed that the mechanical properties of nickel such as ductile, hard, good conductor of electricity and heat are not affected by atmosphere, thus makes it very good in corrosion resistance. In 2008, Singh stated in contrast to nickel properties, aluminum show properties of moderately ductile, very low in density, high malleable and nonmagnetic is the general properties of aluminum.

1.2 Problem Statement

Airless tyre does not have the cushion effect of air like the normal tyre does. It only depends on the suspension effect of the spokes to absorb shock or impact. External force action will start from the tyre surface and it will be transfer to the flexible spokes of the airless tyre. The force will then pass directly to the central hub. Studies had concluded that spokes region are the most risky for failure of hub (Das, 2014). Furthermore, when there is excessive force acting on the tyre, the spokes of the tyre may able to break, thus the hub will also break causing the wheel to be immediately instable (Pandya and Thakkar, 2015). Therefore, hub plays a very important role in tyre mechanism. Figure 1.1 shows the airless tyre design.

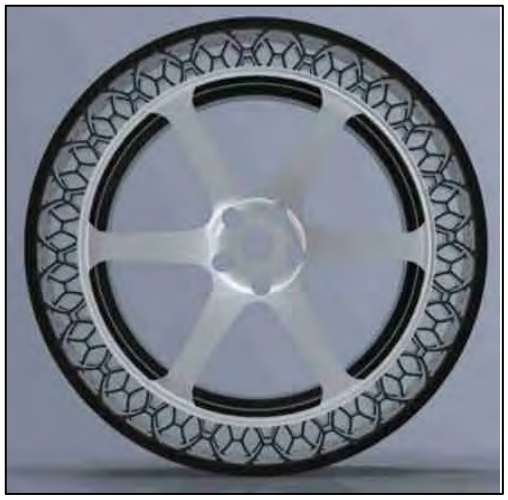


Figure 1.1: Airless tyre design (Sommer, 2009)

Velayudhan and Yameni (2012) found that the existing material of the wheel hub is aluminum. Although aluminum is considered to be lightweight material but its physical strength is relatively smaller which makes the hub able to rupture at certain conditions. Kale (2015) stated that based on the finite element analysis for wheel application, aluminum tend to show a low performance based on the stress induced and displacement. In order to overcome this issues, light weight material which also good in other properties needs to be introduced.

Intermetallic materials are not only lightweight but also possess superior properties such as corrosive resistance, less fuel emission, high physical strength etc. From the literature, intermetallic aluminides are one of the materials having high potential for a wide range of technological application in some essential areas. Thus, the hub part needs a very strong material as it will support more load compared to the existing normal tyre hub. This is due to the impact that it receives and their position in vehicle. Besides that, the design also plays as an important role in wheel performance as it also aid in fuel efficiency (Das, 2014).

1.3 Objectives

The objectives are as follows:

1. To analyze the crystallographic and morphological properties of intermetallic compound (Ni_3Al).
2. To study the mechanical properties of Ni_3Al alloy under heat treatment and non-heat treatment.
3. To study the chemical properties of Ni_3Al alloy under heat treatment and non-heat treatment.

1.4 Scopes of the Research

Intermetallic compounds of Ni_3Al alloy are used as the material to be studies. X-ray diffraction (XRD) will be done to investigate the crystallography of the material. Ni_3Al alloy will undergo surface pre-treatment by using mechanical pre-treatment (grinding and polishing) and chemical pre-treatment (etching) before proceed to testing process. The process of heat treatment use in this research are annealing at four different temperatures which is non-heat treated, 400°C, 500°C and 600°C. Morphology investigation of Ni_3Al alloy will be done by using optical microscope (OM) and scanning electron microscope (SEM). Vickers microhardness and tensile test is done to studies the mechanical properties of Ni_3Al alloy. The chemical properties of Ni_3Al alloy is which is corrosion rate are determined by using Tafel Extrapolation test.

1.5 Significant/Important of Study

There are potential benefits that can be gained by automotive industry after the completion of this study. The properties of Ni_3Al alloy which is light weight, good mechanical properties and excellent corrosion resistance give an advantages for manufacturing wheel hub of airless tyre. The credibility of Ni_3Al alloy was there as it is used widely in structural application and this research opens a new dimension for automotive manufacturer to alternate their current material with Ni_3Al alloy.

1.6 Organization of the Report

This report carries five sections. The introduction of the project is cover in the first chapter. This chapter discusses the background of study, problem statement, objectives, and scope of study. Problems are identified through literature reviews of several related journals and articles. This is followed by objectives to be achieved throughout the study and scope which narrows down the area of the study.

Literature review part is reviewed in chapter 2. This section includes the fundamental hypothesis related to research area and the past investigation that obtained from internet, book, and journal. The current and future materials that can be used in

automotive application along with its interesting properties are also being discussed in this chapter. Lastly, the testing method and mechanical properties of intermetallic compounds are discussed in this chapter.

Chapter 3 contains the methodology part. This chapter explains the flow of the whole project that has been done, starting from literature review to presentation of the final year project. It consist of literature review, identifying materials and process, sample preparation, surface pre-treatment, structural and morphological analysis, mechanical and chemical studies, presentation and report submission.

Chapter 4 contains of results and discussion part. This chapter is most critical part of the research as it contains the finding of the project. The characterization of Ni_3Al alloy was shown here. Brief discussion on the results of the each mechanical and chemical testing at different annealing temperature of Ni_3Al alloy were compared and discuss further in this chapter.

Chapter 5 contains the conclusion and recommendation part. All the findings based on the results in chapter 4 were concluded in this chapter. The conclusion made is based on the objectives. The recommendation for future works also included in this chapter.

CHAPTER 2
LITERATURE REVIEW

Most of this chapter describes the recent research which have been defined and prepared by diverse investigator years before. Interrelated information of older investigations is extracted as references and discussion based on their research about steels, aluminum, possible alternating materials for car parts, intermetallic compounds, structural study, microstructural analysis, mechanical and chemical properties of particular materials.

2.1 Airless tyre

The importance of the wheel‟s contribution to an automotive vehicle cannot overstate (Dixon, 2003). Wheels with tyres are required to produce the forces necessary to control the vehicle. The given wheel is the only means of contact between the road and the vehicle, they are at the heart of the vehicle handling and performance. Knowledge of these characteristics and their effects on automotive performance can give the engineer insight into performance optimization. A firm grasps on what influences a wheel‟s behavior and what these characteristics mean in terms of vehicle dynamics terminology will better prepare the user. An inflatable or pneumatic tyres in any wheel used today started way back in 19th century in the vehicles with the flat surface first and slowly introduced into the tyre pressure (Choudry, 1998). But the tyre pressure is not always constant due to micro air-leak in the tyres which causes reducing the actual pressure in the wheel. This makes the vehicle to work with higher load than the actual. At times due to other factors involved including temperature a catastrophic failure occurs on these vehicles makes complete collapse. In order to overcome these problems, a modular wheel has been introduced especially in military operations (Colin *et al*., 2010). But concern on the common people with respect to the time factor and counter automotive.

2.2 Steels

Steel has been the most used material in automotive industry since a long time ago. The application of steel has allowed automotive company to achieve preferred standards of strength and protection for their cars at quite low prices. In 2009, Matthew reported that steel is normally being used in body in white (BIW) to produce a stiff and strong frame. The basic material that is used to develop automotive body is high strength steel. It is preferred because it is cheap, and yet has exceptional properties like high hardness, yield strength, ultimate tensile strength (Chaman, 1994). Aluminum can save up to 50% of mass over its competing materials such as steels in most applications (Hirsch, 2014). Thus, it can be assumed as the best light-weight material in the automotive industry. Next, steel is famously known among car manufacturing company are because of its properties such as good superficial finish, low cost, high strength and good formability (Toros *et al*., 2008). Interstitial free (IF) steel and micro-alloyed steel are the examples of the most popular steels sheets quality in the automotive industry. The application of sheet depends on the point of use in automotive industry (Mihaliková *et al*., 2016). Pahlevani *et al*. (2017) stated that waste materials from the formation of ceramic surface in situ on normal carbon steel by heat treating process can be apply to increase the wear resistance while at the same time lessen the demands on expensive coating.

Steel remains the most used material by industry regardless of competition from other materials from local or overseas in twenty first eras. The aim such as steel offer protection, durability recyclability, strength, and value has made steel to become the most popular material in car industry (Steven, 1997). Steel is no longer preferred cars material any longer even all the advantages stated before. One of the major practical design plans for successful vehicles efficiency light weighting is through material substitution. In addition, material substitutions are usually affective in reducing the weight of car than structure alteration. Steel is replicated too heavy as it fulfills 25% percent weight of the whole frame of car. Carle and Blount (1999) stated that complementary addition of features from time to time owed to growing client request was instantaneously adding the density ratio per unit car.

2.3 Aluminum Alloy

Nowadays car manufacturer has begun to acknowledged aluminum as important materials. In 2007, Wang and Li stated that the characteristic of aluminum which makes it as the optimum for automotive industry are decent mechanical properties, low mass, great oxidization resistance and recycling prospective. In 1995, Hoyle studied shows that by substitute"s aluminum with steels, the car will have less fuel consumption generate fewer polluting radiations, and rusting free. It is recorded that raw steel is five times cheaper in price compared to aluminum. Carle and Blount (1999) demonstrated that standard frame of car are less in quality compared to the luxurious car brand such as BMW and Mercedes since they used advanced aluminum car body. Research found that size, design and density of the car will enhance the protection and handling when accident is occurred. In terms of cost, budget or normal car model are about three times cheaper than advanced automotive. SiC, Al/TiB_2 and Al_2O_3 reinforced with functionally graded aluminum alloy display excellent hardness and tensile strength at the high particle outer region of the sample (Radhika and Raghu, 2016).

Even though aluminum has shown a lot of advantages in their properties, but this materials needs reliable joining method. It has been recorded that hot cracks and porosity are common defect while joining process take place (Löveborn *et al*., 2017). In 1994, Lowe concluded that different in quality of aluminum compared to steel are aluminum is more capable to withstand impact in real life accident which cannot be duplicated simply by any other material especially steel. Carle and Blount (1999) discovered that one of disadvantages of aluminum is difficulty in handling process. To achieve the desired strength of aluminum, some of aluminum alloy needs to get through heat treatment process and get preserved first. Not to forget is the cost to apply aluminum alloy in bulk sheet in automotive industry will involve a huge cost. For example aluminum 7075 have aluminum and zinc as alloying constituent which is the zinc additions are range from 0.8 to 12.0 %. These alloys are generally used in high performance uses such as aircraft, aerospace and competitive sporting gear.