# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# MECHANICAL AND THERMAL PROPERTIES OF INTERMETALLIC $NI_5AL_3$ FOR AUTOMOTIVE BODY APPLICATIONS

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

by

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FACULTY OF MANUFACTURING ENGINEERING

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# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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TAJUK: **MECHANICAL AND THERMAL PROPERTIES OF INTERMETALLIC $Ni_5Al_3$ FOR AOTOMOTIVE BODY APPLICATIONS**

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# APPROVAL

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# DECLARATION

I hereby, declared this thesis entitled "mechanical and thermal properties of intermetallic $Ni_5Al_3$ for automotive body applications" is the results of my own research except as cited in references.

Signature : ...............................................

Author's Name : LIM KOK CHIN

Date : 09th APRIL 2010

# ABSTRACT

Intermetallic alloy $Ni_5Al_3$ is known for its good magnetic and thermal properties as the candidate materials for thermistor applications. A research work on their mechanical and thermal properties study give a better understanding of this system in automotive bodies' materials. Hardness and corrosion testing were carried out to determine the surface hardness and corrosion rate of $Ni_5Al_3$. There are one non-heat treated and three annealing samples prepared for each test. The annealing temperatures are $300^oC$, $500^oC$, and $700^oC$ respectively. The thermal effects on the hardness value and corrosion rate were interpreted. Then, the experimental results were analyzed and compared to the current automobile bodies' materials. Besides, XRD and EDX inspection were done to mainly investigate the composition of Ni and Al in this alloy. $Ni_5Al_3$ is estimated to have hardness of approximately 400 HV and corrosion rate ranging from 5.0 to 30 x $10^{-3}$ mm/yr, thus expected to be a qualified material for replacing current automobile bodies' materials.

# ABSTRAK

*Intermetallic alloy* $Ni_5Al_3$ merupakan bahan yang sesuai untuk pembuatan termistor kerana telah menunjukkan sifat-sifat magnetik dan terma yang baik. Pengkajian ke atas sifat-sifat mekanikal dan terma $Ni_5Al_3$ akan memberikan pemahaman yang lebih mendalam terhadap aplikasi-aplikasi $Ni_5Al_3$ dalam bidang automasi, terutamanya sebagai bahan pembuatan strucktur kereta. Ujian kekerasan dan kakisan telah dijalankan untuk mendapatkan maklumat tentang kekerasan dan kadar kakisan bahan ini. Setiap ujian dibahagikan empat sampel. Antaranya, tiga sampel akan dibakar pada suhu 300$^{o}$C, 500$^{o}$C, dan 700$^{o}$C sebelum ujian dimulakan. Kesan-kesan pembakaran akan diselidik dan bacaan yang terkumpul akan dibandingkan dengan bahan pembuatan badan automasi terkini. Ujian XRD dan EDX juga akan dijalankan untuk menentukan komposisi Ni dan Al dalam bahan ini. $Ni_5Al_3$ dijangkakan mempunyai kekerasan berhampiran 400 HV dan kadar kakisan dalam jurang 5.0-30 x $10^{-3}$ mm/tahun, oleh itu, dijangkakan untuk mempunyai potensi yang baik sebagai gentian kepada bahan pembuatan badan automasi sekarang.

# DEDICATION

I dedicated this report to my research supervisor, P.M. Dr. TJS Anand and my fellow friends. Without their patience, understanding, and support, the completion of this work would not have been possible.

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| | | |
|---|---|---|
| ASTM | - | American Society for Testing and Materials |
| ELV | - | End-of Live Vehicle |
| FCC | - | Face Centered Cubic |
| HSS | - | High Strength Steel |
| SEM | - | Scanning Electron Microscopy |
| TEM | - | Transmission Electron Microscopy |
| UTeM | - | University Teknikal Malaysia Melaka |
| XRD | - | X-ray Diffraction |
| EDX | - | Energy Dispersive X-ray Spectroscopy |
| HFHSS | - | Hot Forming High Strength Steel |
| AHSS | - | Advanced High Strength Steel |
| CR | - | Penetration Rate |
| MR | - | Mass Loss Rate |
| EW | - | Equivalent Weight |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

The mechanical properties and thermal behaviour of non-heat and annealed $Ni_5Al_3$ alloys were studied by mechanical testing included hardness test and corrosion test. The main objective of this research is to determine the potential of $Ni_5Al_3$ as candidate for automobile bodies as there were still space of improvement in automotive area, especially from the aspect of car weight reduction and fuel emission reduction. Results analysis and statistical comparison were made to reveal the advantages (or disadvantages) of $Ni_5Al_3$ against current automotive car bodies material, which is mainly high strength steel or low carbon steel. It is expected that $Ni_5Al_3$ will be a suitable candidate for automobile bodies mechanically but not economically due to its high cost (nickel and aluminium are generally more expensive than steels).

## 1.2 Background

Nowadays, the major trend of automobile body fabrication aimed in cost reduction while retaining the high quality aspects of safety, functional operations, and others specifications. A complete car body might be consisted of various types of materials according to the specific requirements of each part. However, the predominant metal is high strength steel which is known of its good mechanical and thermal properties such as strength, fracture toughness, and thermal stability. In most case, aluminum was introduced to reduce the total car weight as well as to aid in corrosion resistance. The use of aluminum seemingly has solved the car weight problems; nevertheless aluminum is very expensive, which in another way, increase the cost of raw material.

Intermetallic compounds which are also known for its superior thermal properties and good mechanical properties can be a potential candidate as alternative automobile bodies' material. Intermetallic compounds offered a compromise between ceramic and metallic properties when hardness and/or resistance to high temperature are important enough to sacrifice some toughness and ease of processing. Therefore, an intermetallic compound is generally brittle with high melting point. By the way, intermetallics can also display desirable magnetic, superconducting, and chemical properties, due to their strong internal order and bonding (metallic and covalent/ionic). Nickel based alloy is one of the intermetallics which has low density and low cost, comparatively. The Ni-Al binary phase diagram contains five intermetallic compounds which are $Al_3Ni$, $Al_3Ni_2$, $Al_3Ni_5$, NiAl, and $Ni_3Al$. Among these intermetallics, NiAl and $Ni_3Al$ have by far received the vast majority of scientific attention as they are considered candidate materials for high temperature structural and coating applications. This is not surprising considering that these compounds have the highest melting points in the Ni-Al binary system, relatively low densities (densities of aluminum and nickel are 2.7 $g/cm^3$ and 8.8 $g/cm^3$ respectively, while the density of iron is 7.85 $g/cm^3$), good strength and high temperature corrosion and oxidation resistance. However, the research will focused on the mechanical and thermal study of $Ni_5Al_3$ intermetallic. In the present paper, an investigation on mechanical and thermal properties of $Ni_5Al_3$ utilized for automobile body application will be reported.

## 1.3 Problem Statement

Generally, automotive car body is made of high strength steel with carbon content ranging from 0.05 to 2.0 % and small quantity of others alloying elements such as manganese, nickel, chromium, molybdenum, and etc. The combination of all these elements (including steel) compromised high toughness, strength, hardness, melting temperature, and good corrosion resistance. However, steel is heavy with density ranging from 7.75-8.05 $g/cm^3$ based on the alloying constituents. The weight of car directly affected the movement and speed of a car. A car with heavier car body will required larger energy (horse power) to start up and to speed up. Following this, the fuel consumption will also increased in order to burn and supply more energy (power) to a car.

The alternative way to solve the above problems is to introduce a lighter material into a car body. For this purpose, many of the car manufacturers have introduced a quantity of lightweight aluminum into car body. However, here come arises of another issues, where the aluminum is much expensive than steel, and that tends to increase the cost. Besides, the maximum amount of aluminum allowed is limited in order to retaining the strength and hardness of a car body as aluminum is known as very ductile and soft metal. Aluminum also has lower melting temperature than high strength steel, and this would reduced the thermal stability (structural changes, for example: soften) of car body against crash with subsequent high enough of heat generated.

Coping with the encountered problems as mentioned above, the present research will investigate the mechanical and thermal properties/behavior of $Ni_5Al_3$, a Ni-Al intermetallic compound, and determine the potential of this intermetallic as a suitable alternative for automobile bodies' material.

## 1.4 Objectives

The objectives of the research project are to:

1. To study the mechanical and thermal properties of intermetallic compound, $Ni_5Al_3$ by carried out laboratory testing: hardness testing, heat treatment, and corrosion testing.
2. To analyze the above obtained results and determine the potential of $Ni_5Al_3$ as the candidate material for automobile body through comparison of $Ni_5Al_3$ with the current automobile bodies' material from the aspects of hardness, tensile strength, and corrosion rate.

## 1.5 Scope of Study

The research project preliminary focuses on investigating the mechanical and thermal properties of intermetallic compound, $Ni_5Al_3$ by performing paperwork research and laboratory experiments. Then, the relevant mechanical and thermal testing will be carried out using proper testing methods, parameters, and instruments. After that, analysis of the obtained experimental results is performed and finally, discussion and conclusion are made regarding the feasibility of $Ni_5Al_3$ applied as automobile body material based on the results obtained.

## 1.6 Importance of Study

The research seeks to find out a candidate material with compromise mechanical and thermal properties to replace the current car body materials. The current car body material, high strength steel, which is heavy has directly caused more fuel consumption and indirectly aggravates environmental pollution. Scientists have anticipated that people will run out of petroleum in the future. Therefore, lowered fuel consumption of vehicles not only to save money but also to save petroleum from exhausted.

# CHAPTER 2

## LITERATURE RIVIEW

### 2.1 Introduction

The literature review chapter included some past studies on the $Ni_5Al_3$ and development of automobile bodies, which are relevant to the present research. It also included a summary on those past researches.

### 2.2 Background of $Ni_5Al_3$

The $Ni_5Al_3$ phase was first observed in a $Ni_{63.8}Al_{35.2}Co_1$ alloy by Enami and Nenno at 1978. They suggested an ordered orthorhombic unit cell based on the FCC lattice and with space group $D^{19}_{2h}$. This unit cell was later confirmed in pure $Ni_{65.3}Al_{34.7}$ by Khadkikar and Vedula who determined the lattice parameters to be a=0.7475 nm; b=0.3732 nm; and c=0.6727 nm [Schryvers et al. (1995)]. From these parameters, a basic nearly tetragonal lattice is apparent (a≈2b) and the small deviations from tetragonality are neglected in most cases. Microstructural studies suggested that the $Ni_5Al_3$ phase can form from the Llo structure by a simple reordering at temperatures as low as 300$^o$C while the main morphology of the martensite plates and their internal twinning remains unchanged [Potapov et al. (1997)].

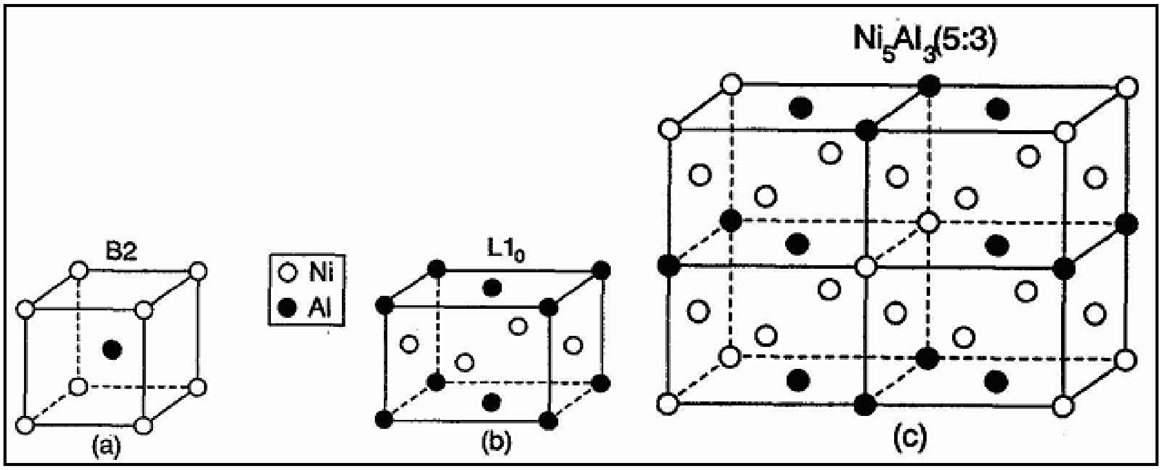


**Figure 2.1:** Crystal structure of various phases in Ni rich Ni-Al alloy [Potapov et al. (1997)].

## 2.3 Peritectoid Formation of $Ni_5Al_3$

$Ni_5Al_3$ can be observed by tempering the Ni-Al alloy martensite between 300 and 400$^oC$. According to the phase diagram, this phase is stable below the peritectoid temperature, $T_p$ of about 700 $^oC$. The stability range of this phase was established between 64 and 68 at % Ni. According to the phase diagram, the phase $Ni_5Al_3$ should be produced by a peritectoid reaction from the phases NiAl and $Ni_3Al$, but until now this phase was only obtained by annealing the martensite phase below the peritectoid temperature or by precipitation from the NiAl matrix [Sengelhoff and Koster (1997)].

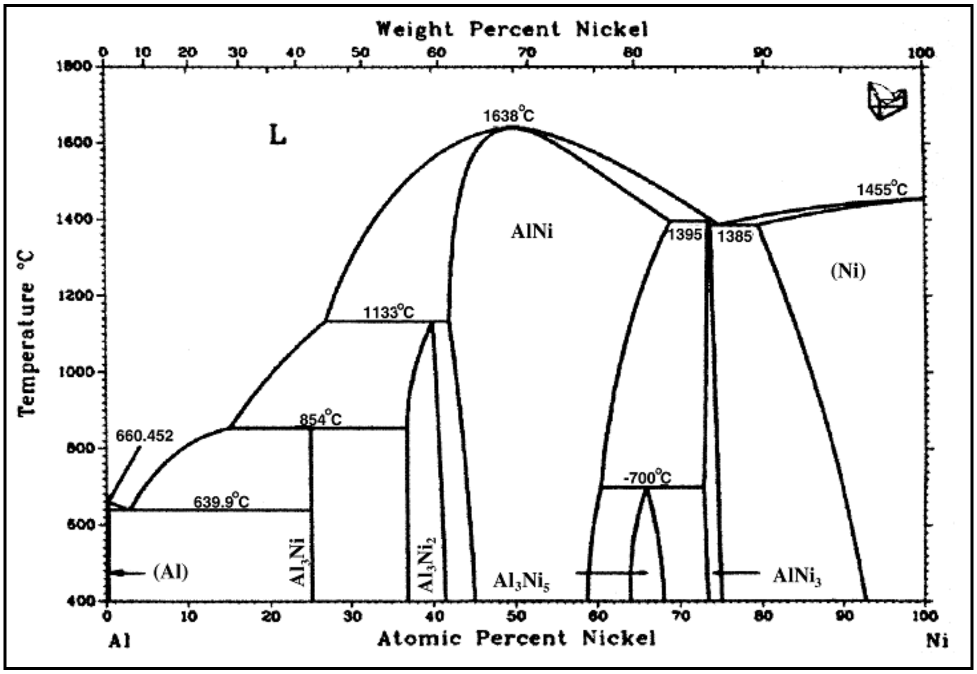


**Figure 2.2:** Phase diagram of Ni-Al alloy [Morsi (2001)].

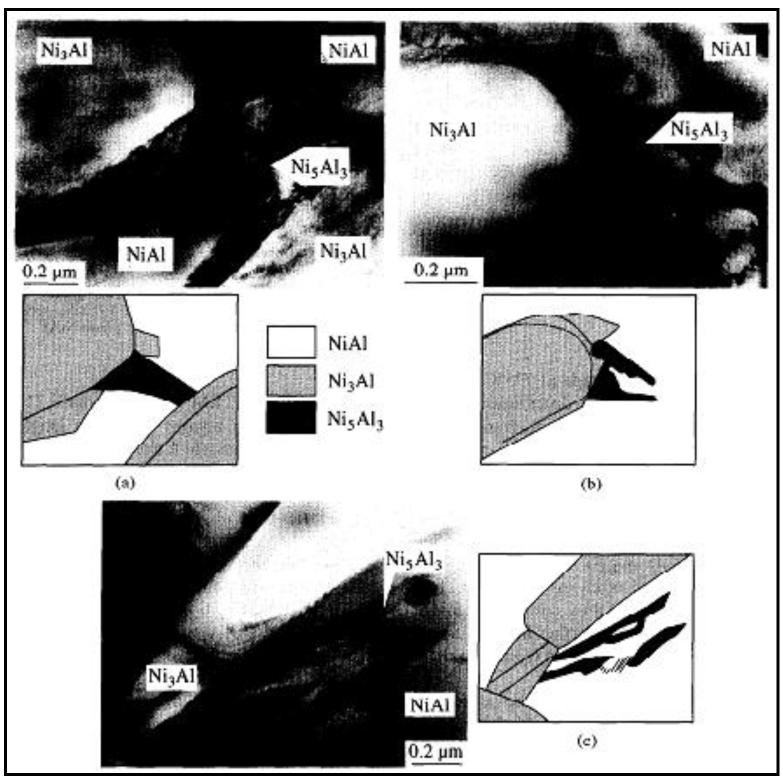


**Figure 2.3:** Bright field TEM images showing the formation of $Ni_5Al_3$ (a) at a grain boundary of NiAl (500 °C 3 days); (b) nucleation of $Ni_5Al_3$ at the NiAl/$Ni_3Al$ interface and (c) further growth of $Ni_5Al_3$ into NiAl (480 °C 14 days) [Sengelhoff and Koster (1997)].

## 2.4 Effect of $Ni_5Al_3$ Phase on Mechanical Properties of Martensitics Ni-Al Alloys

The $Ni_5Al_3$ phase is usually considered as a harmful phase to the mechanical properties and shape memory effect of Ni-Al-based alloys. The stress-strain curve of Ni-24.1 at.% Al-18.2 at.% Fe specimens quenched from 1250 $^oC$ is shown in Figure 2.4, where two yielding stages are clearly seen. As shown in Figure 2.5, the first yielding stress of aged specimens decreased with the aging temperature increased from 200 to 400 $^oC$, and increased as the aging temperature increased higher than 400 $^oC$. The first yielding stress decreased with the increase of martensitic transformation temperature, and vice versa. These results are reasonable since the first yielding stress is related to the reorientation of martensite variants [Xie and Wu (2000)]. Unsatisfactory low-temperature mechanical properties and a complicated phase composition at the boundaries of NiAl (β), $Ni_5Al_3$, and $Ni_3Al$ (γ') make the application of NiAl problematic so far [Czeppe and Wierzbinski (2000)].

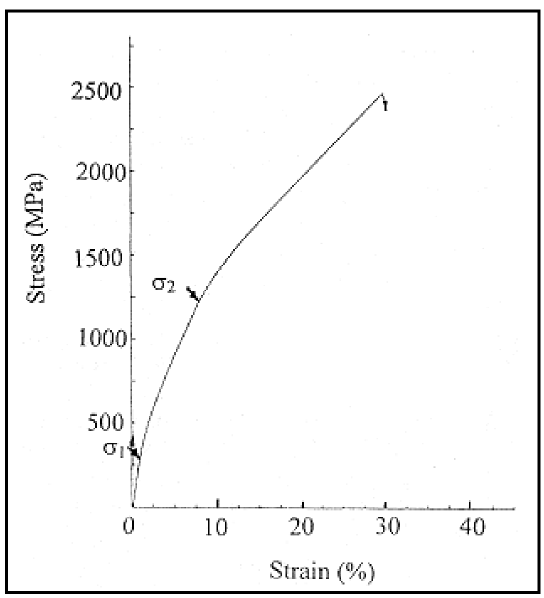


**Figure 2.4:** Stress-strain curve of Ni-Al-Fe quenching from 1250 $^oC$ [Xie and Wu (2000)].

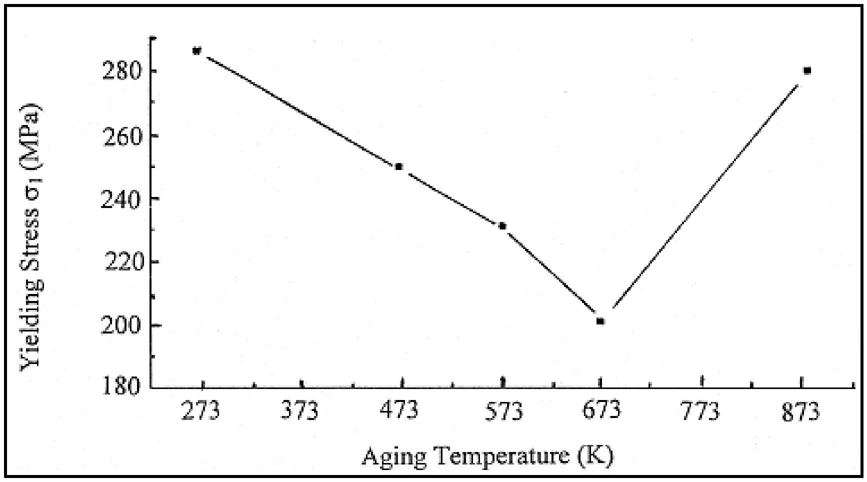


**Figure 2.5:** Yielding stress and the aging temperature of Ni-Al-Fe specimens [Xie and Wu (2000)].

## 2.5 Controversies Surrounding the $Ni_5Al_3$

Robertson and Wayman (1984) stated that the grain boundary brittleness of the beta phase is greatly alleviated when it is annealed to precipitate $Ni_5Al_3$, but no experiment results were provided. Accompanying the abnormal increase of resistivity and the formation of $Ni_5Al_3$, the yielding strength and hardness are significantly increased by approximately 100%, while the ductility and shape memory effect are severely degraded [Yang and Wayman (1993)].

The effect of temperature on the tensile strength of a Ni-Al composite produced from 0.25mm thick Ni and 0.15 mm thick Al foils was investigated and showed in Table 2.1 and Figure 2.6 below. It was found that the tensile strength of Ni-Al composite is directly proportional to the volume percent aluminide layer [Alman et al. (1995)].