UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MECHANICAL AND THERMAL PROPERTIES OF INTERMETALLIC NiAl 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 Materials) with Honors.

by

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2010

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Mechanical and Thermal Properties of Intermetallic NiAl for Automotive Body Applications.**

SESI PENGAJIAN: 2009/10 Semester 2

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This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Materials) with Honors. The member of the supervisory committee is as follow:

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ABSTRACT

This project presents a study on the mechanical and thermal properties of intermetallic NiAl for automotive body applications. The fuel consumption and weight problems have influenced the vehicle development. Hence, a material replacement is an effective method to decrease the automobile lightweighting and fuel consumption. Intermetallic, NiAl is considering one of the materials to replace the automotive body because intermetallic NiAl has good mechanical and thermal properties such as high melting point, low density, excellent oxidation resistance and good thermal stability. Various tests such as hardness test, corrosion test and fatigue test was used to study the properties of intermetallic NiAl material. Besides that, the NiAl material was involved in an annealing heat treatment process. The temperature ranges were 300°C, 500°C and 700°C. This process was to heat the material with the desired temperature after that the composition of NiAl specimens were checked by energy dispersive X-ray spectroscope and X-ray diffraction machine. Furthermore, lattice constant of non-heat treated and heat treated NiAl was calculated by the information obtained from the EDX and XRD graph. The NiAl materials mechanical and thermal properties were compared before and after the heat treatment process. In addition, the experimental results of NiAl were compared with the material of current automotive body. The hardness result of NiAl from the experiments had shown that heat treatment with 700°C had the highest value compared to non-heat treated, 300°C and 500°C which achieved 438.0 HV. Besides that, non-heat treated NiAl had the lowest corrosion potential which was -0.420 V. The corrosion potential was increased due to the increased of heat treated temperature. NiAl had low electrode potential and corrosion current density and this indicate that NiAl was difficult to corrode. On the contrary, intermetallic had major drawback such as brittleness. A further development was studied for the improvement of NiAl.

ABSTRAK

Kajian untuk sifat-sifat mekanikal dan haba bagi Intermetallic NiAl supaya digunakan dalam badan automotif telah dipersembahkan dalam projek ini. Harga Minyak dan berat kereta merupakan salah satu masalah yang mengaruhkan pembangunan kereta. Oleh itu, pengantian oleh bahan yang baru merupakan salah satu cara yang berkesan untuk mengurangkan berat automotif dan harga minyak. Intermetallic NiAl dianggap sebagai satu bahan baru untuk menggantikan badan automotif adalah kerana intermetallic NiAl mempunyai sifat-sifat mekanikal dan haba yang baik sebagai contohnya, takat lebur yang tinggi, ketumpatan yang rendah, rintangan pengoksidaan yang baik dan pemantapan haba yang bagus. Banyak kajian seperti kajian kekerasan, kajian kakisan dan kajian fatigue telah dijalankan untuk mengkaji sifat-sifat bahan intermetallic NiAl. Selain itu, intermetallic NiAl juga melibatkan dalam proses pemanasan annealing. Suhu yang telah digunakan dalam projek ini adalah 300°C, 500°C dan 700°C. Komposisi intermetallic NiAl akan diperhatikan dengan bantuan energy dispersive X-ray mikroskop dan X-ray diffraction mesin selepas dipanaskan dalam proses annealing dengan suhu yang ditetapkan. Sifat-sifat mekanikal dan haba telah dibandingkan sebelum dan selepas pemanasan dalam proses annealing. Selain itu, kajian-kajian NiAl yang telah dijalankan dibanding dengan bahan yang digunakan untuk membina badan automotif. Spesimen yang telah dipanaskan dengan suhu 700°C mencapai kekerasan yang paling tinggi iaitu 438.0 HV. Selain itu, spesimen yang tidak dipanaskan mempunyai nilai rintangan kakisan yang agak tinggi iaitu -0.420 V. NiAl mempunyai sifat-sifat mekanikal dan haba yang baik. Tetapi, NiAl mempunyai beberapa kelemahan seperti rapuh. Pengajian yang lebih lanjut diperlukan untuk membaiki kelemahan NiAl.

ACKNOWLEDGEMENTS

I would like to express profound gratitude to my Final Year Project Supervisor, Professor Madya Dr. T.J.S Anand for his invaluable support, encouragement, supervision and useful suggestions throughout this project. His technical support and continuous guidance enabled me to complete my project successfully. I am also highly thankful to Mr. Sivarao, the Coordinator of the Final Year Project for his valuable suggestions and briefing during the beginning.

I am grateful for the co-operation of the staff and technician at campus for willing to answer my question and gave me so much important data and information without any hesitation.

I am as ever, especially indebted to my parent, Mrs. Teh Ah Lan for her love and support throughout my life.

Phang Chee Kong

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

ASTM	-	American Society for Testing and Materials
Al	-	Aluminum
BCC	-	Body Center Cubic
CR	-	Corrosion Rate
CVD	-	Chemical Vapor Deposition
CO_2	-	Carbon Dioxide
CsCl	-	Cesium Chloride
E_{corr}	-	Electrode Potential
EDM	-	Electricaldischarge machining
EDX	-	Energy dispersive X-ray spectroscopy
EW	-	Equilibrium Weight
HFHSS	-	Hot Forming High Strength Steel
HV	-	Vickers Hardness
i_{cor}	-	Corrosion current density
MOD	-	Metal Organic Deposition
MR	-	Mass Loss Rate
NaCl	-	Sodium Chloride
Na_2SO_4	-	Sodium Sulfate
NiAl	-	Nickel Aluminide
Ni	-	Nickel
PVD	-	Physical Vapor Deposition
rpm	-	Revolution per Minute
U.S.	-	United States
XRD	-	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Introduction

Public concern about energy consumption has influenced vehicle development for over three decades. The car industry faces a fuel consumption and crucial weight problem resulting from increasing customer demands in terms of safety and engine performance. The fuel consumption and weight problem can be achieved by structure modification or material replacement. The automobile body structure modification requires the changes of forming, welding and assembling systems which are costly. On the other hand, material replacement is generally more effective in automobile lightweighting and fuel consumption reduction than structure modification. Car bodies contribute more than 40% to the total weight of a car and light metal is seen as a good opportunity to decrease the body in weight decisively. Therefore, a new light material is studied in this paper.

An intermetallic compound can be defined as an ordered alloy phase formed between two metallic elements and this alloy is made up of nickel combined with aluminum. Intermetallic, Nickel Aluminide (NiAl) is a combination of 50 percent weight of Nickel and 50 percent weight of Aluminum. NiAl is studied and used as lightweighting material to replace the material of high strength steel. Intermetallic, NiAl has been of particular interest due to their excellent high temperature properties such as high melting point due to the stable ordered structure, strength and corrosion resistance. Besides that, NiAl has good mechanical properties such as good creep properties, high strength and low density.

1.2 Problem Statement

Over the past of 20 years, total vehicle weights have risen significantly. Cars are getting heavier and bigger every new generation. Luxury, safety and electrical equipments have been added to the standard vehicles. Every year the average weight of vehicles increases by 16 kilograms. With their direct influence on the power demand of vehicles, the reduction of weight is one among other measures in order to improve fuel economy and addressing range, performance, size, cost and Carbon dioxide (CO_2) emission.

Fuel economic has gained a dramatic importance. The price of fuel has increases time by time. The increasing of the fuel will directly influence the fuel consumption of vehicles. A reduction of 100 kilograms in the body weight reduces fuel consumption by approximately 0.5 liters per 100 kilometers.

According to the environmental studied of European Union, transport accounts for 26% of global CO_2 emissions and is one of the few industrial sectors where emissions are still growing. Car use is one of the principle contributors to greenhouse gas emissions from the transport sector. The more usage of fuel consumption affect the environment seriously and because of environmental issues, particularly important is the reduction of exhaust gas from automobiles that accounts for 20 to 30% of CO_2 emission. It was legislated in Europe to control CO_2 emission at below 140g/km, a reduction of 25% over 1995, after 2008.

Automotive accident is a common issue that happened all the time in the world and automotive accident always caused injury or death to driver if the automotive body cannot reduce the collision force during crashing. Furthermore, a high temperature will produce during the collision of the car and the high temperature will change the properties of the car body such as the high temperature will decrease the hardness of the car body. Hence, the increased of the temperature will affected the safety of the car body.

Therefore, the properties of a new intermetallic NiAl is studied and used as an advanced material for the replacement of automotive body to decrease the weight of the car body, fuel consumption and emission of carbon dioxide, CO_2. Besides that, thermal properties of intermetallic NiAl is studied and used to improve the safety of automotive.

1.3 Objectives

The objectives of this project are to:

1. To study the mechanical properties of intermetallic NiAl material and apply it on the automotive as body replacement.
2. To study the properties of intermetallic NiAl material by using of various tests such as hardness test, corrosion test, X-ray diffraction analysis and Energy dispersive X-ray analysis.
3. To determine the mechanical properties of intermetallic NiAl material after heat treated by various temperature as an improvement of car safety.
4. To analyze and compare the results with the current automotive body materials such as mild steel, steel sheet and high strength steel.

1.4 Scope

This project involves the determination of the mechanical properties and thermal properties of the intermetallic NiAl material by various types of tests. The raw material will be machined into specify specimens with the parameter in the ASTM. This project will study the mechanical properties such as hardness, tensile strength, fracture toughness and thermal properties such as melting point of the material after that the result will compare to the existing car body material.

1.5 Importance of Study

This project is very important to the automobile sector in order to see the possibility of reducing the weight of the car, performance, cost, size and environmental. Besides that, an optimum combination of body structure and material is highly required and thus an exact evaluation of good mechanical properties of material has been also demanded. In addition, the new material can be used to replace the exhausting earth metal such as steel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will summarize the theory of the project to be studied. Besides that, it will also include the studied made by the researcher in the past.

2.2 The Revolution of Car Body

Wood used in conjunction with fabric has been referred to already and was the construction of the bodywork of many cars in the 1920s before its replacement by steel. For outer panels this was of fairly thick gauge between 0.9 and 1.00 mm. Gradually a change took place- due to weight and cost reduction studies the average thickness of external panels reducing progressively to 0.8 mm in the 1950s/1960s and to the current level of 0.7 mm in use today for the production of the body of unitary construction. According to Geoff (2003) the internal parts for structural members range from 0.7 to 2.0 mm, the scope for down gauging over the years being limited by stiffness constraints.

On the other hand, Erica et al. (2006) stated that steel has been the materials of choice for automobiles since Henry Ford's introduction of mass production in 1913. This history of steel in the automobile has lead not only to numerous jobs in the U.S., but also to a wealth of technological experience on body component design, production, and assembly with steel. In 2004, the average light vehicle produced in

North America contained 2233 pounds of steel, totaling 55% of the weight. Another 331 pounds, or 8%, of typical light vehicle in 2004 was iron.

In addition, for past 50 years Aluminum has been considered an alternative material to steel and instances can be recalled of it being used for models in the early 1900s and volume production in the 1950s, but until recently economics, both initial material and processing costs, have discouraged widespread adoption. A general rule 5 was that the net cost of aluminum assemblies after allowances for density, equivalent section, modified processing, etc., was double that of steel although weight could be halved. This has been broadly proven and vehicle structures have demonstrated that compared with the 25 per cent weight reduction achievable with steel, savings of nearer 50 per cent can be obtained with aluminum. Besides that, the use of polymers in U.S. automotive applications has risen dramatically from an average of 18 pounds per vehicle in 1960. Ward's Motor Vehicle Facts and Figures place plastics and composites at 335 pounds in the average light vehicle produced in 2004, or 8% of vehicle weight, and 4.5% of total U.S. plastic consumption. Geoff (2003) has noted that most of the plastic applications in vehicles are lower-performance commodity polymers and short-fiber composites. These lower performance polymers are used in sport side truck models in fascia, fenders, and trims, and in heavy truck applications for cab steps, bumpers, spoilers, doors, fenders, toolbox doors, and even full cabs.

2.3 The Definition of Intermetallic

Intermetallic materials are a unique class of materials having characteristics of both metals and ceramics. They differ from conventional metal alloys in that they generally posses long range ordered crystal structures. Intermetallic can be defined as a compound of two metals that has a distinct chemical formula. Tomasz & Stanislaw (2000) had shown the first recorded reference to the NiAl compound appeared in a phase diagram study published in 1908, where the unusually high melting temperature of this phase was noted.

During the last 15 years, intermetallic have received enormous interest in materials science and technology with respect to applications at high temperature and a new class of structural materials is expected to be developed on the basic of intermetallic.

However, several of intermetallic has uses in many sector such as aerospace, machine and etc.

2.4 Structure of NiAl

2.4.1 Crystal Structure

Intermetallic has a stronger bond between different atoms compare to the similar atoms. Accordingly, intermetallic forms particular crystal structures and the atoms are distributed in an orderly fashion. Besides that, Tomasz & Stanislaw (2000) have verified that polycrystalline NiAl exhibits a brittle to ductile transition at temperature range from 573 to 873K which is significantly lower than other intermetallic compounds; the exact temperature depending on the stoichiometry, impurity content and grain size. But the unsatisfactory of low temperature mechanical properties and a complicated phase composition at the boundaries of NiAl, Ni_5Al_3 and Ni_3Al phase fields, makes the application of NiAl problematic so far.

Zhang J.M. et al. (2008) have stated that the crystal structure of an intermetallic material is determined by the strength and character of the bonding, which depends on the particular electronic configuration. NiAl is a well ordered intermetallic compound with the B2 (CsCl prototype) structure, which consists of two interpenetrating simple cubic cells, where Al atoms occupy the cube corners of one sublattice and Ni atoms occupy the corners of the other sublattice. This unit cell is shown in Figure 2.1.

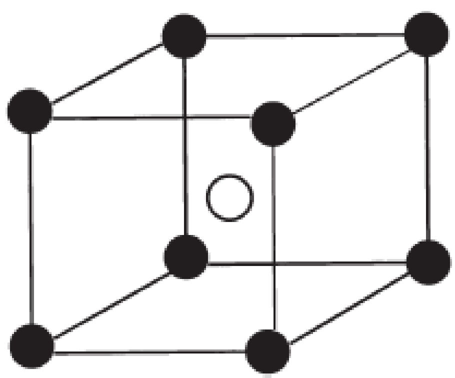

Figure 2.1: Unit cell of NiAl; Al atoms (open circles) are on body centers and Ni atoms (filled circles) at corners.

2.4.2 Lattice Parameter

Hughes et al. (1971); Taylor & Doyle (1972) had proved the lattice parameter of NiAl is 0.2887 nm. A maximum in the lattice parameter occurs at the stoichiometry composition. According to Fraser et al. (1973), some studies had shown a lattice parameter maximum at slightly Al rich compositions, these observations were probably due to inadequate control over the chemistry of the alloy and inaccurate methods of determination of the composition. Furthermore, Dey G.K. (2003) has noted that variation in density as a function of composition has been examined in the case of NiAl and it has been observed that the density of NiAl increases linearly with composition with increasing Ni content. The NiAl composition dependence of lattice parameter such as density has been used to interpret the nature of lattice defects especially point defects exist in the intermetallic compound. Georg & Ralf (2008) verified that density increases and lattice parameter decreases with the increasing Ni content has been noticed on the Ni rich side. On the other hand, the density decreases and the Al content lattice parameter are more rapid on the Al rich alloy side. The B2 structure is shown on Figure 2.2

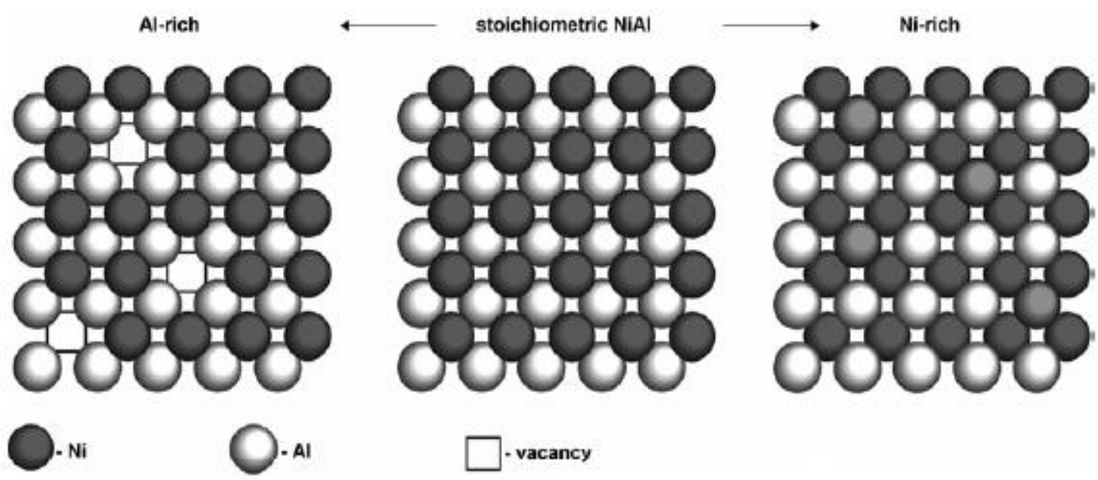

Figure2.2: Atomic defect structures of B2 ordered NiAl as a function of stoichiometry.

2.4.3 Phase Stability

Kubaschewski (1958) acknowledged that NiAl has one of the largest negative heats of formation among the intermetallic compounds with B2 structure. Its heat of formation has been found to depend on composition, the largest value being that of the stoichiometry composition indicating excellent stability for this composition. According to Noebe et al. (1997), consistent with the strong Ni-Al nearest neighbor bonds, it has been observed that significant order existed in NiAl up to the melting temperature and no irrefutable proof has been obtained so far to suggest than an order-disorder transformation occurs in this alloy. Besides that, Mori et al. (1984) has proved that the degree of intrinsic disorder α' is the usual parameter that has been applied for establishing the degree of order in this intermetallic compound. But stabilize of the B2 structure causes the NiAl very difficult to disorder. Furthermore, the other attractive aspect of NiAl is that it cannot be disordered even by heavy ion bombardment at very low temperature -258°C (15K).

2.4.4 Crystal Defect

Neumann et al. (1976) has noted NiAl belongs to the category of intermetallic with a B2 structure where A atoms sit on β sites and vacancies on α sites. At the stoichiometry composition, materials having this kind of defect structure have a triple defect structure because three defects must exist simultaneously, two vacancies on the α sites and one A atom on a β site. The occupancy of Al sublattice is always full. Hence when there is excess Ni, it occupies the Al sublattice with no significant composition dependent vacancy concentration occurring in either sublattice. However, when Al is in excess, vacant sites or constitutional vacancies are formed in the Ni sublattice. It is not known whether Al can substitute Ni on the Ni sublattice in case of Al rich compositions. It has been shown in many studies that antistructure defects on the Ni sublattice are energetically unfavorable and are very unlikely. Parthasarathi & Fraser (1984) have mentioned a high concentration of thermal