UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Investigation of Mechanical Properties of Aluminium 2024 – Stainless Steel 304 Composite

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for the Degree of Bachelor of Engineering (Honours) Manufacturing (Engineering Material)

By

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BORANG PENGESAHAN STATUS TESIS*

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APPROVAL

This report 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 Material). The members of the supervisory committee are as follow:

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ABSTRACT

The purpose of investigation of mechanical properties of aluminium-ferum composite developed to investigate the mechanical properties aluminium 2024 reinforced continuous stainless steel 304 fibers. This study investigates the mechanical properties of the composite with 3mm spacing of continuous fiber. Pressureless metal infiltration by casting used to produce the composite. The composites properties compared to aluminium 2024. To make a comparison, investigation of mechanical properties of composites which is tensile test and charpy impact test conducted under ASTM D3552 and E23 standard. The SEM machine also used to study the interphase between matrix and reinforcement. From the testing, aluminium 2024 reinforced stainless steel 304 have higher tensile strength, modulus of elasticity and toughness compared to unreinforced aluminium 2024. Besides that from the surface observation, there was an interphase and interface between the matrix and reinforcement.

ABSTRAK

Projek ini dijalankan bertujuan mengkaji sifat mekanikal komposit aluminium 2024-stainless steel 304. Komposit aluminium 2024-stainless steel 304 dihasilkan melalui kaedah *Pressureless metal infiltration by casting*. Sifat mekanikal komposit ini dibandingkan dengan aluminium 2024. Untuk membuat perbandingan sifat mekanikal, ujian hentaman charpy dan ujian tegangan dijalankan mengikut standard ASTM E23 dan D3552. SEM machine juga digunakan untuk mengkaji *interphase* diantara matrik dan fiber. Daripada ujian yang dijalankan, komposit aluminium 2024-stainless steel 304 mempunyai sifat tegangan, elastik dan kekuatan yang lebih tinggi berbanding aluminium 2024. Melalui kajian permukaan komposit yang dijalankan, didapati terdapatnya pembentukan *interphase* diantara matrik dan fiber.

DEDICATION

For all your advice and encouragement, this thesis is gratefully dedicated to my family and my friends. Thank you very much for your continuous support and effort towards the publication of this thesis.

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

%	-	Percent
σ_f	-	Tensile Strength of the Fiber
τ_c	-	Shear yield Strength of the Matrix
σ_y	-	Yield Strength,
σ	-	Tensile Strength
ASTM	-	American Society for Testing and Materials
CMC	-	Ceramic Matrix Composites
CNC	-	Computer Numerical Control
^{0}C	-	Degrees Celsius
D	-	Diameter
E	-	Modulus of Elasticity
l	-	Critical Length
l_c	-	Critical Length of a Fiber
M	-	Mega
MMC	-	Metal Matrix Composites
Mm	-	Milimeter
NA	-	Not Available
Pa	-	Pascal
PMC	-	Polymer Matrix Composites
s	-	Second
SEM	-	Scanning Electron Microscope
TIG	-	Tungsten Inhaled Gas

CHAPTER 1
INTRODUCTION

1.1 Research Background

The investigation of mechanical properties of aluminium-ferum composite is the research developed to study the mechanical properties of aluminium 2024 reinforced continuous stainless steel 304 fibers composite. It emphasizes the study on mechanical behavior of aluminium 2024 reinforced with continuous stainless steel 304 fibers composite with 3mm spacing and unidirectional arrangement.

Aluminium metal matrix composites are one of several classes of advanced materials which are expected to play a significant role in the development of future aerospace, automotive and military applications. Due to the availability of high performance continuous fibers, these composites exhibit much improved properties. Especially, continuous metallic fibers, like molybdenum, stainless steel, and tungsten that have the advantages of high strength, good ductility, large flexibility, and thus easiness to weave. By using continuous fibers in aluminium metal matrix composite, the material properties improved *in terms of specific strengths, stiffness at room and elevated temperatures and good wear resistance, compared to unreinforced structural materials such as commercial metals and alloys.*

Pressureless metal infiltration by casting is a process to produce the composite. The aluminium 2024 reinforced stainless steel 304 properties were compared to unreinforced aluminium 2024 to study the material properties. To obtain the mechanical properties, tensile test, and charpy impact test conducted under ASTM standard to determine the toughness, tensile strength, yield strength and

modulus of elasticity. Besides that the interface observation also conducted to study the surface between matrix and reinforcement.

1.2 Statement of the Purpose

The purpose of this research is to study and analyze the mechanical properties of aluminium 2024 reinforced stainless steel 304 and unreinforced aluminium 2024 as a comparison. The mechanical properties parameters observed are tensile properties and impact properties.

1.3 Hypotheses

a) The reinforcement will increase the material properties.
b) The interphase will be form when matrix infiltrates and embedded the reinforcement.

1.4 Problem Statements

The aluminium metal matrix composites commonly used discontinuous fiber as reinforcement; the problems that widely occurred during processing are; non uniform of fibers distribution (Matthews & Rawlings, 2002). By change the fiber usage to continuous fiber, the fiber distribution can be arranged uniformly (Liang *et al.* 2005). The mechanical properties of the material produce need to be investigate.

1.5 Objectives

The objectives of this project are:

a) To investigate the mechanical properties of aluminium 2024 reinforced continuous stainless steel 304 fibers.
b) To compare the mechanical properties of aluminium 2024 reinforced continuous stainless steel 304 fibers with unreinforced aluminium 2024.
c) To study and analyze the interphase surface of aluminium 2024 reinforced with continuous stainless steel 304 fibers composite.

1.6 Scope of Study

This study focus on the investigations of mechanical properties of aluminium 2024 reinforced continuous stainless steel 304 fibers composite. The properties of composite compared with unreinforced aluminium 2024. The reinforcement fibers arranged to 3mm spacing. The composite produced by pressureless metal infiltration by casting method. Tensile test and impact test conducted to investigate the mechanical properties of composite in longitudinal direction. The testing used to obtain the tensile strength, modulus of elasticity, yield strength and toughness. SEM machine used to study the interphase surface of composite.

CHAPTER 2
LITERATURE REVIEW

2.1 Composites

A composite is a combination of two or more material that can be arranged to be reinforcement or matrix. The combination forms a useful material to increase the properties of materials. The chemical reaction between reinforcement and matrix form an interface and interphase that separating them insoluble in each other. Figure 2.1 shows the formation of component in composite material. Composite have three categories which is polymer matrix composite, ceramic matrix composite, metal matrix composite.

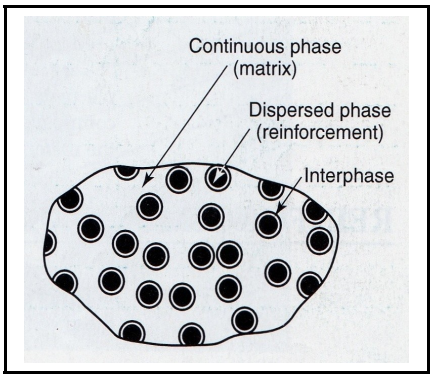

Figure 2.1: Formation in Composite Material

Source: Helsel & Liu (2001)

2.2 Matrix

Matrix is a one part of composite that used to surround the reinforcement material. The matrix can be polymer, metal and ceramic. It acts as medium to support and protect the reinforcement the matrix protects the individual fibers from the surface damage because of mechanical abrasion or chemical reaction with the environment. It avoids brittle cracks from fiber to fiber and serves as a barrier to crack propagation (Callister, 2003). Usually matrix have a lower density, stiffness, and strength compared to reinforcement material but when the matrix combine with reinforcement material it produces high strength, and stiffness and still low in density.

2.2.1 Metal Matrix Composites

Metal matrix composite (MMC) commonly used a ductile and light metal as a matrix such materials include aluminium, magnesium and titanium. For high temperature applications, cobalt and cobalt-nickel alloy widely used.

When matrix embedded the reinforcement, reinforcement may improve the specific strength, specific stiffness, abrasion resistance, creep resistance, thermal conductivity and dimensional stability. MMC also can be operate in higher temperature, non flammability and greater degradation by organic fluids compared to PMC, but the MMC much more expensive than PMC. Compared to unreinforced material, MMC have greater strength but they have much lower ductility and toughness. MMC with fiber reinforced are excellent conductors of heat and electricity because the heat or electrical current is transmitted from fiber to fiber efficiently.

The reinforcement for MMC can be particulates, continuous, discontinuous and whiskers. Commonly used of Continuous fiber materials include carbon, silicon carbide, boron, alumina, and the refractory metals. The concentrations of

reinforcement normally range between 10% and 60%. Discontinuous reinforcements consist primarily of silicon carbide whiskers, chopped fibers of alumina and carbon, and particulates of silicon carbide and alumina.

Although MMC improve the material properties but the cost of MMC restricted the use of MMC. MMC application widely used in military, automotive and aerospace, in automotive industry MMC used to produce automotive disc brakes especially for high performance cars such as Lotus and Porsche. Honda also applied MMC in their cars, aluminium MMC used to produces the H22A, H23A, F20C, F22C, and C32B engines. Toyota, Lotus, Porsche, and Yamaha also used MMC in their engines. MMC also used to produce engines driveshafts to increase rotational speeds and reduced vibration noise levels. Extruded stabilizer bars, forged suspension and transmission components also used MMC in automotive application. In aerospace application The F-16 Fighting Falcon uses monofilament silicon carbide fibers in a titanium matrix for a structural component of the jet's landing gear and Space Shuttle Orbiter used boron fiber reinforced aluminium alloy matrix as structure. In military application, some tank armors made from metal matrix composites, probably boron nitride reinforced steel matrix. Boron nitride is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel. Jacobs & Kilduff, (2001).

2.2.2 Polymer Matrix Composites

Polymer matrix composites (PMC) is the composite that using polymer in a resin type as a matrix to surround the reinforcement. Polymer matrix has largest applications and large quantity because of its light properties in ambient temperature, ease of fabrication and cost.

Polymer resin can be thermoset or thermoplastics but thermoset is the most common polymer resins for commercial used because of its properties that resistance to heat and chemical reaction (Helsel and Liu, 2001). Besides that they have greater

dimensional stability than thermoplastics. Thermoset matrices that widely applied in PMC is Polyester, bismaleimides, and Vinyl ester that used with glass fiber reinforcement. Epoxies used for aerospace components because they have better mechanical properties and resistance to moisture compared to Polyester and Vinyl Ester but the Epoxies application needs high cost. For high temperature applications, the Polyimide is used because of its upper temperature limit reach to 450 ºC (230ºC). For the future aerospace application the matrix will be using are Polyetheretherketone (PEEK), Polyphenylene Sulfide (PPS), and Polyetherimide (PEI) which are the high temperature thermoplastic resins. Glass, carbon, and aramids are the most common fiber reinforcement that combined with polymer matrix. Boron, Silicon Carbide, and Aluminium Oxide also used as reinforcement but it has low degrees. (Callister, 2003)

The PMC applications have been used in military aircraft components, helicopter blades, and some sporting equipments by using Boron fiber reinforced polymer composites. Silicon carbide and alumina fibers are utilized in tennis rackets circuit boards, and rocket nose cones. The Table 2.1 shows the general characteristics of thermoset and thermoplastic matrices.

Table 2.1: General Characteristics of Thermoset and Thermoplastic Matrices

General Characteristics of Thermoset And Thermoplastic Matrices					
Resin type	Process Temperature	Process Time	Use Temperature	Solvent Resistance	Toughness
Thermoset	Low	High	High	High	Low
Toughened Thermoset	↕	↕	↕	↕	↕
Lightly Cross-linked Thermoplastic	↕	↕	↕	↕	↕
Thermoplastic	High	Low	Low	Low	High

Source: Helsel & Liu (2001)

2.2.3 Ceramic Matrix Composites

Matrix of ceramic matrix composite (CMC) commonly made from glass. The most popular ceramic matrix are lithiumaluminasilicate (Li_2O-Al_2O_3-SiO), BMAS (BaO-MgO-Al_2O_3-SiO) and magnesia-alumina-silicate (MgO-Al_2O_3-SiO) and commonly reinforced with fiber, whiskers, or particulates of silicon carbide (SiC), Silicon nitride (Si_3N4), Zirconium Oxide (ZrO_2), Aluminium Oxide (Al_2O_3) or other engineered ceramics. Helsel and Liu (2001).

Ceramic matrix composites are used to improve the fracture toughness of ceramic itself, because the fracture toughness of ceramic materials is low which is between 1 and 5 Mpa √m (14 to > 140 ksi √in.). The reinforcement materials in ceramic matrix composites increase the fracture toughness to 6 and 20 Mpa √m (5.5 and 18 ksi √in.). (Callister, 2003) Ceramic matrix also have a high strength at high temperature (refer table 2.3), low thermal conductivity and very hard.

The ceramic matrix composite widely applications are cutting tools, bearings, seals, heat engines, diesel engine component, gun barrel liners, and aircraft gas turbine engine.

2.3 Reinforcement

The reinforcement is the phase of the composite that primarily responsible for the structural properties of composite. Reinforcement phase providing structural properties include strength and stiffness. The reinforcement generally in the shape of fiber, whisker, or particulate.

2.3.1 Fiber Reinforcement