UNIVERSITI PUTRA MALAYSIA

MECHANICAL PROPERTIES OF THE AS-CAST QUARTZ PARTICULATE REINFORCED LM6 ALLOY MATRIX COMPOSITIES

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By

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In the Memory of

My Father, Allahyarham Fadhil Aziz

And

Allahyarham Saputra Zamani, Afzal Zikri

And

Special Dedication to

My Mother, H. Cut Nurlaila

My Wife Malahayati

And

My Daughter, Nyak Intan Fazilati and Nyak Qurratu Aini

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Chairman : Associate Professor Shamsuddin Sulaiman, PhD

Faculty : Engineering

Metal matrix composites are engineered materials combine two or more materials, one of which is a metal, where the tailored properties can be attained by systematic combination of different constituents. A variety of methods available for producing these advanced materials includes the conventional casting process which is considered as the easiest processing technique. Preparation of these composite materials by foundry technology have the unique benefit of near-net shape fabrication in a simple and cost effective manner. Besides, casting processes lend themselves to manufacture large number of complex shaped components of composites at a faster rate required by the automotive, transportation, sports and other consumer oriented industries. In this study, quartz-silicon dioxide particulate reinforced LM6 alloy matrix composites were fabricated by carbon dioxide sand molding process by varying the particulate addition by volume fraction on percentage basis. Tensile and hardness tests and scanning electron microscopic studies were conducted to determine the maximum load, tensile strength, modulus of elasticity and

fracture surface analysis to characterize the morphological aspects of the test samples after tensile testing. Hardness values are measured for the quartz particulate reinforced LM6 alloy composites and it has been found that it gradually increases with increased addition of the reinforcement phase. The tensile strength of the composites decreases with the increase in addition of quartz particulate. In addition, particulate-matrix bonding and interface studies have been conducted to understand the mechanical behavior of the processed composite materials and it were well supported by the fractographs taken by the scanning electron microscope. The fractographs taken after the tensile test illustrates the particle pullout from the matrix due to lack of bonding and load deformation characteristic mechanism.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIFAT MEKANIKAL BAGI ZARAHAN AS-CAST QUARZA YANG DIPERKUAT LM6 ALOI MATRIK KOMPOSIT

Oleh

M. SAYUTI

Oktober 2005

Pengerusi : Profesor Madya Shamsuddin Sulaiman, PhD

Fakulti : Kejuruteraan

Besi matrik komposit merupakan bahan kombinasi kejuteraan dua atau lebih bahan, salah satu dari padanya adalah logam, dimana kandungan yang dibuat boleh dicapai dengan kombinasi sistematik pelbagai bahan. Pelbagai kaedah yang sedia ada untuk mencipta bahan termaju ini, termasuk proses acuan konvensional yang dianggap sebagai teknik/proses yang paling mudah. Penyediakan bahan komposit ini dengan teknologi peleburan mempunyai kebaikan unik dengan bentuk fabrikasi "near-net" yang mudah dan jimat, selain itu proses acuan membantu dengan sendiri untuk mengeluarkan komponent berbentuk komplek yang besar komposit pada tahap yang cepat yang diperlukan oleh pihak automotif, pengangkutan, sukan dan lain-lain industri yang tumpukan pada cita rasa pengguna. Dalam kajian ini, quarza-zarahan silikon dioksida yang dikukuhkan dengan komposit matrik LM6 aloi bertetulang di fabrikasikan dengan proses pengacuan pasir karbon dioksida dengan mengubah campuran (zarahan) dengan kandungan berpandukan pada peratusan. Ujian tegangan dan ujian kekerasan serta mikroskop electron

imbasan telah dilaksanakan bagi menentukan berat masimum, kekuatan tegangan, modulus kekenyalan dan setelah ujian tarikan, dilakukan analisis permukaan patah untuk mengenal pasti ciri-ciri morfologi sample ujian. Nilai kekerasan bagi komposit aloi LM6 diperkuat zarahan kuarsa dan dapat disimpulkan bahawa, ia berkurangan dengan campuran bertambah dengan fasa penguatan. Kekuatan tegangan komposit berkurangan dengan pertambahan zarahan kuarza. Sebagai tambahan ikatan matrik dan kajian antara muka telah dijalankan bagi memahami proses kelakuan bahan mekanikal komposit dan ia telah di sokong oleh fraktograf yang diambil dengan mikroskop electron imbasan. Fraktograf yang diambil selepas ujian tegangan menunjukkan penarikan zarahan dari matriks, oleh kerana kekurangan ikatan dan mekanisme ubah bentuk beban.

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I convey my thanks to all of my colleagues, friends, housemate and UPM support staff.

M. SAYUTI

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LIST OF ABBREVIATIONS

ASTM – American Society for Testing and Materials

Al – Aluminum

A – length of reduce section (mm)

B – length of grip section (mm)

C – width of grip section (mm)

C – Carbon

Cu – Copper

G – gage length (mm)

L – overall length (mm)

Mn – Manganese

P – Phosphorus

R – radius of fillet (mm)

S – Sulfur

T - Ton

Si – Silicone

Z_n – Zink

V – volume (cc)

W – width (mm)

m – mass (kg)

t – thickness (mm)

ρ – density (gr/cm^3)

MPa – Mega Pascal

kN – kilo Newton

MMC – metal matrix composite

SEM – scanning electron microscope

S_iO_2 – silicon dioxide (quartz)

LM6 – Type of aluminium

μm – micrometer

v_c - Volume fraction of composite (%)

v_f - Volume fraction of fiber (%)

v_m - Volume fraction of matrix (%)

ρ_c - Density of composite (gr/cm^3)

ρ_f - Density of fiber (gr/cm^3)

ρ_m - Density of matrix (gr/cm^3)

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CHAPTER 1

INTRODUCTION

1.1 Background

Industrial technology is growing at a very rapid rate and consequently there is an increasing demand and need for new materials. The metal-non metal composites represent a class of materials which can with stand high temperature and pressure besides its resistance to radiation effects and chemical reactivity. Metal matrix composites (MMC) are composed of an element or alloy matrix in which a second phase is embedded and distributed to achieve some property improvement. Based on the size, shape and amount of the second phase, the composite properties of the varies. Particulate reinforced composites, often called as discontinuously reinforced metal matrix composites, constitute 5 – 20 % of these new advanced materials. The microstructure of the processed composites influences and have a great effect on the mechanical properties. Generally, increasing the volume fraction of the second phase (reinforcement phase) in the matrix leads to an increased stiffness, yield strength and ultimate tensile strength. But the low ductility of particulate reinforced MMCs is the major drawback that prevents their usage as structural components in some applications [Rizkalla and Abdul.W, 1997]. Miller and Humpherys [1990] have carried out a detailed investigation on the strengthening mechanism of composites. They have found that the particle size and its volume fraction in metal matrix composites influences the generation of dislocations due to thermal mismatch and as well as the effect influenced by the developed residual and internal stresses. The researchers have predicted that the dislocation density is directly proportional to the volume fraction and also due to the amount of mismatch. The resulting strengthening effect (quench strength) is proportional to the square root of the dislocation density. Consequently, this effect would be significant for fine particles and for higher volume fractions. Recent studies have shown that the matrix microstructure has a clear effect on the fracture details of the tested specimen.

Metal matrix composites have outstanding benefits due to the combined metallic and ceramic properties, thereby yielding improved physical and mechanical properties. Among the various types of MMCs, particulate-reinforced composites are the most versatile and economical one [Sharma et al., 1997].

During the past 40 years, materials design has shifted emphasis to pursue light weight, environment friendliness, low cost, quality, and performance materials. Parallel to this trend, metal-matrix composites have been attracting growing interest. MMC attributes include alterations in mechanical behavior (e.g., tensile and compressive properties, creep, notch resistance, and tribology) and physical properties (e.g., intermediate density, thermal expansion, and thermal diffusivity) by the reinforced filler phase. Apart from these advantages, MMCs have limitations on thermal fatigue, thermochemical compatibility, and posses lower transverse creep resistance [Ejofor and Reddy, 1997].

Fabrication of discontinuously reinforced Al-based MMCs can be achieved by standard metallurgical processing methods like powder metallurgy, direct casting, rolling, forging and extrusion, and further the products can be shaped, machined and drilled by using conventional machining facilities. Thus, they can be made available in suitable quantities particularly for automotive applications [Seah et el., 2003].

Composite materials are characterized by good mechanical properties over a wide range of temperature. The choice of the processing method depends on the property requirements, cost factor consideration and future applications prospects [Kaczmar et al., 2000].

Composite materials with a metal or an alloy matrix can be produced either by casting or by powder metallurgy methods. Metal matrix composites (MMC) are considered as potential material candidates for a wide variety of structural application in the transportation, automobile and sport goods manufacturing industries due to the superior range of mechanical properties they possess [Hasyim et al., 2003].

According to Cok [2004], metal matrix composites (MMC) represent a new generation of engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties including specific strength, specific stiffness, wear resistance, corrosion resistance and elastic modulus. MMCs combine metallic properties of matrix alloys (ductility and toughness) with ceramic properties of reinforcements (high strength and high modulus), leads to greater strength in shear and compression and higher service-temperature capabilities. Thus, they have significant scientific, technological and commercial importance. During the last decade, because of their improved properties, MMC are being used extensively for high performance applications such as in aircraft engines and more recently in the automotive industries.

Aluminium oxide and silicon carbide powders in the form of fibers and particulates are commonly used as reinforcements in MMCs and the addition of these reinforcements to aluminum alloys has been the subject of a considerable amount of research work. Aluminium oxide and silicon carbide reinforced aluminum alloy matrix composites are applied in the automotive and aircraft industries as engine pistons and cylinder heads, where the tribological properties of these material are considered important. Therefore, the development of aluminum matrix composites is receiving considerable emphasis in meeting the requirements of various industries. Incorporation of hard second phase particles in the alloy matrices to produce MMCs has also been reported to be more beneficial and economical [Kok, 2004] due to its high specific strength and corrosion resistance properties. Metal matrix composites are materials that are attractive for a large range of engineering applications.

1.2.Problem statement

In the past, various studies have been carried out on metal matrix composites. SiC, TiC, TaC, WC and B4C are the most commonly used particulates to reinforce metal or alloy matrix or matrices like aluminium or iron, while the study of silicon dioxide reinforcement in LM6 alloy is still rare and scarce. However, very limited studies have been reported and so the information and the data available on the mechanical properties and fracture surface analysis is scarce and hence makes this study a significant one. In this investigation quartz particulate reinforced LM6 alloy matrix composites test samples fabricated and processed by casting method are selected. So in this research work the parameter of different percentage of S_iO_2 particulate addition in the LM6 alloy matrix is examined to study the mechanical behavior and fracture surface characteristic used tensile testing of the processed specimens.

1.3. Research objectives

The overall objective of this experimental investigation is to study the technical viability of S_iO_2 particulate reinforced LM6 aluminium alloy matrix composites and the specific objectives are as follows:

1. To determine the ultimate tensile strength and modulus of elasticity and hardness of S_iO_2 particulate reinforced LM6 alloy matrix composites.

2. To study the morphological features and characteristics of the fracture surfaces of the quartz reinforced LM6 alloy composites subjected to tensile testing by using scanning electron microscope (SEM).

1.4. Scope and limitation

In this project, LM6 alloy is used as a matrix material due to its better fluidity and castability. It contains 11-13% silicon as a major alloying element in the aluminium metal. It is an eutectic alloy having the lowest melting point as per the aluminium-silicon equilibrium phase diagram and available at reduced cost in the market. CO_2 process in employed to produce sand moulds for casting S_iO_2-particulate reinforced LM6 alloy composites. The advantages of CO_2 sand cast products possess good dampening properties, uniform strength in all directions and cheaper when compared to other manufacturing processes such as forging, welding, and rolling.

In this study, tensile testing and scanning electron microscopy are employed to evaluate the maximum load, young's modulus, tensile strength and to characterize the morphological features of the fracture surfaces in silicon dioxide (quartz) - particulate reinforced LM6 alloy composites after the tensile testing.

1.5.Thesis layout

This thesis has been structured into 5 chapters. The first one is the introduction chapter and chapter 2 presents a review of literature that relates to the investigation on the mechanical behavior of SiO_2-particle reinforced LM6 alloy matrix composites. Chapter 3 presents the description of research methodology. The experimental results on tensile testing of the processed specimen and the fracture surface characteristic features after the tensile testing are presented in chapter 4. For the tensile test and SEM analysis an overall discussion is made and explained in chapter 4. The final conclusions of this study are mentioned in chapter 5 precisely.