FABRICATION & PROPERTIES OF ALUMINIUM-SILICON CARBIDE (Al/SiC) COMPOSITE MATERIAL

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ABSTRACT

A composite material is the material that consisting of two or more chemically or physically specific phase. The reinforcing component is distributed in continuous or matrix components. When the matrix is metal, the composite is namely metal matrix composite (MMC). In this research study, the metal matrix used is aluminium while the fiber material used is silicon carbide. So, when these two distinct materials combined it will form as aluminium-silicon carbide (Al/SiC) composite. The main objective of this research is to study the behavior of Al/SiC composite in different ceramic composition under various compaction loads. The fabrication of homogenous Al/SiC composite material consists several processes in powder metallurgy technique. The main step of powder metallurgy are mixing and blending, compacting and sintering. The mixing and blending process begin with prepare both powder material which is varies in weight percentage of SiC. After that, the mixed powders were pressed through compaction process in a 30mm diameter cylindrical steel die by using the hydraulic press machine under three different compaction loads. And lastly, all the specimens were sintered in a furnace to a fixed temperature, 500°C. This research study is completed by the characterization and mechanical testing. The specimens are characterized and the microstructures of the composites were studied by using the optical microscope. After that, the hardness of composites was tested by using Vickers Micro-Hardness Testing machine. The conclusion gained from this study is the different ceramic composition under various compaction loads plays significant influences in determining the performances of the Al/SiC composite material. The differences in ceramic compaction under various compaction load affect the data gained in density differentiate before and after sintering process, hardness test and microstructure in Al/SiC composite material.

ABSTRAK

Bahan komposit adalah bahan yang terdiri daripada dua atau lebih fasa secara kimia atau fizikal tertentu. Komponen tetulang disebarkan dalam komponen berterusan atau matriks. Apabila matriks adalah logam, komposit ini dinamakan logam matriks komposit (MMC). Dalam kajian penyelidikan ini, matriks logam yang digunakan ialah aluminium manakala bahan gentian yang digunakan ialah silikon karbida. Jadi, apabila kedua-dua bahan yang berbeza digabungkan ia akan membentuk seperti aluminium-silikon karbida (Al/SiC) komposit. Objektif utama kajian ini adalah untuk mengkaji kelakuan Al/SiC komposit seramik dalam komposisi yang berbeza di bawah pelbagai beban pemadatan. Fabrikasi homogen Al/SiC bahan komposit terdiri beberapa proses dalam teknik pemprosesan serbuk. Langkah utama pemprosesan serbuk terdiri daripada pencampuran dan pengadunan, pemadatan dan pensinteran. Pencampuran dan proses pengadunan bermula dengan menyediakan kedua-dua bahan serbuk yang berbeza dari segi peratusan berat SiC. Selepas itu, serbuk campuran telah ditekan melalui proses pemadatan dalam 30mm diameter acuan keluli silinder dengan menggunakan mesin hidraulik di bawah tiga beban pemadatan yang berbeza. Dan akhir sekali, semua spesimen telah disinter dalam relau pada suhu tetap, 500°C. Kajian penyelidikan ini selesai dengan pengujian mekanikal. Spesimen yang mempunyai ciri-ciri dan mikrostruktur bagi komposit telah dikaji dengan menggunakan mikroskop optik. Selepas itu, kekerasan komposit telah diuji dengan menggunakan mesin Ujian Vickers Micro-Kekerasan. Kesimpulan yang diperoleh daripada kajian ini adalah komposisi seramik yang berbeza di bawah pelbagai beban pemadatan memainkan pengaruh yang besar dalam menentukan prestasi bahan komposit Al/SiC. Perbezaan dalam pemadatan seramik di bawah pelbagai beban pemadatan menjejaskan data yang diperolehi dalam kepadatan membezakan sebelum dan selepas pensinteran proses, ujian kekerasan dan mikrostruktur dalam Al/SiC komposit.

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LIST OF SYMBOLS

Pa	Pascal
μm	micrometer
mol	molecule
g	mass
cm	centimeter
ton	Mass or Volume
kgf	Kilogram-force
F	Force
D	Diameter
ρ	Density
V	Volume

LIST OF ABBREVIATIONS

PM	Powder Metallurgy
MMC	Metal Matrix Composite
CMC	Ceramic Matrix Composite
PMC	Polymer Matrix Composite
Al_2O_3	Aluminium Oxide
NaOH	Sodium Hydroxide
HV	Hardness Value
Al	Aluminium
SiC	Silicon Carbide

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

When the two or more dissimilar material combined physically and chemically it was called composite material. The reinforcing component is distributed in continuous or matrix components. These combinations are known as metal-matrix and ceramic-matrix composite. Metal matrix composite (MMC) is named when the matrix used is metal. Aluminium, titanium, copper and other super alloys are the common used metal in a metal matrix composite. While the fiber materials is graphite, silicon carbide, tungsten and boron. The composite materials significantly improve the strength, stiffness, weight and toughness.

As said before, the matrix-metal composite is the combination of matrix metal and fiber material. So, the matrix is the monolithic material into which reinforcement is embedded and it is completely continuous. It means, there is a path through the matrix, unlike two materials sandwiched together. Usually, a lighter metal have been used as a metal matrix which gives a flexible support to the reinforcement. The fiber material is embedded into the matrix. The fiber material usually act as a reinforced which improve the physical performance of material such as wear resistance, thermal conductivity and friction coefficient.

In this project, the metal matrix used is aluminum and the fiber material is silicon carbide. So, when these two components combined it will be form as aluminum-silicon carbide (Al/SiC) composite. The Al/SiC designed specimens will be prepared by using powder metallurgy technique. There are three basic steps namely, mixing powder according to its pre-designed, blending and compact pre mixing powder, and lastly is sintering. The blended powders are then press and compact into a die. A die with specific dimension will be used for powder compaction at room temperature. After the compaction complete it will goes to the sintering process with the specific temperature.

This powder metallurgy techniques offers good dimensional control and the finishing operation can be eliminates. Even though this process is having high cost in tooling it can reduces scrap and waste.

1.2 PROBLEM STATEMENT

When these two different materials combined, with large contrast in material properties are bonded, there are many defects and failure will occur during fabrication and operation. The three basic process to produce this Al/SiC composite is by using powder metallurgy involve are mixing the materials, blending and compaction, and lastly sintering. The problems are usually occurs during the sintering process because of the aluminum has low melting point while silicon carbide has high melting point. So, these two dissimilar materials cannot perform well during sintering process.

1.3 OBJECTIVES

The aim of this study was to improve the defects and failure that will occur during fabrication and characterization by using the powder metallurgy process. The study objectives include:

i) To design and fabricate the metal-matrix composite, namely Aluminum-Silicon Carbide (Al/SiC) system by using powder metallurgy process.
ii) To characterize the fabricated Al/SiC composites.

iii) To understand the effect of ceramic composition on the behavior of Al/SiC composite material under various compaction load.

1.4 SCOPES

In this project, the Al/SiC composite specimen will be fabricating by using the powder metallurgy process. The basic process are involving three steps which are; mixing and blending the powder, compaction, and sintering. On the mixing the metal and the ceramic powder process, there are few parameter will be monitored. Same goes to the compaction of metal powder and sintering which have their own parameters that will be monitored for example, temperature and compaction load.

When the powder metallurgy process had completely done, the process of characterization must be done. This process is carrying out by using an optical microscope. It was conducted to study the distribution of ceramic reinforcements in the designed specimen. The Al and SiC element in Al/SiC microstructure must be recognizes.

After doing the characterization process, there was the mechanical testing to be done. The effect of weight percentage of ceramic concentration of the composite can be investigated by using micro-hardness test. The micro-hardness test is conducted commonly by using the Vickers Hardness Tester.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Based on some research before this which is related to the composite material, powder metallurgy and aluminium-silicon carbide will be reviewed in this chapter. Composite material was discussed generally at the early part in this chapter. And then, continued with the process used in this study which is powder metallurgy process and lastly is about aluminium-silicon carbide which is the material used in this project.

2.2 COMPOSITE MATERIAL

Materials that are frequently used and reach their limit of usefulness are in the process for improved their own performance, which specified by several criteria such as having less weight, more toughness and strength and lower cost. Because of that, materials engineer and scientist are always struggling to improve the some traditional materials to become a new product or to produce completely one new material. Composite materials are one of the examples from the latter category (Matthews and Rawlings, 1999).

A combination of two or more dissimilar materials that are physically and chemically combine together which results in better compared to material that are not bonded with others are called composite material. The two important element is composite material are reinforcement and a matrix. Composite materials are having their own benefits which are high strength, low density and having a less weight in the finished part (F.C. Campbell, 2010). The addition of straw to clay to make bricks for buildings is the one of the previous example of composites along 15 years ago. In this consolidation, the straws act as the reinforcing fibres and the matrix is clay. Composite materials have used in wider application in aircraft, space vehicles, satellites, automobile and sporting goods (Kalpakjian and Schmid, 2010).

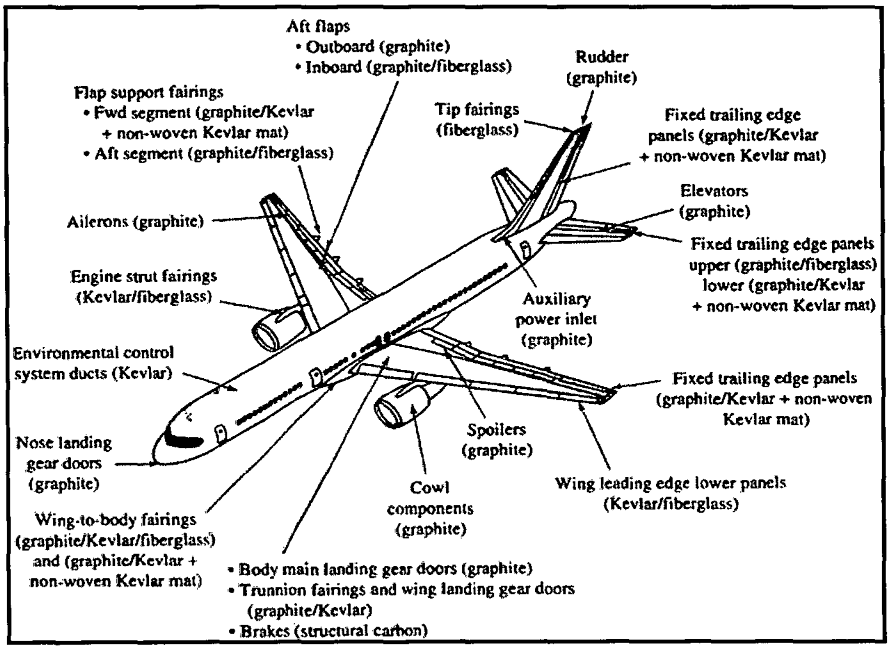

Figure 2.1: Application of advanced composite materials in Boeing 757-200 commercial aircraft.

Sources: Courtesy of Boeing Commercial Airplane Company.

Commonly, one component will be a matrix in which the reinforcing phase is distributed. Thus matrix component usually be a continuous phase. There were called as a metal matrix composite (MMC), if the metal as the matrix component. The reinforcing material can be either in short fibres, continuous fibres or in whisker form. The composite materials have their own characteristic which can be determine by the three components which is reinforcement, matrix and interface. The matrix was a medium or binder to hold and maintaining the strong and stiff fibres or other types of reinforcement in the proper orientation (M. Cahn, 2005).

2.2.1 Metal Matrix Composites (MMCs)

During 1970s, there were considerable research into boron fibre reinforced alloys was carried out which leads to aerospace application. There was a problem on chemical reaction between boron and its matrix at temperature above 600°C according to the fabrication techniques. Recently, the inert fibres like silicon carbide and alumina have enabled liquid metal processing routes to be developed. However, most of MMCs are still in developing stage and not so extensively produced as the polymer matrix composite (Mathews and Rawlings, 1999).

For quite some time, metal matrix composite materials have been found applied in many areas of our daily life. Metal matrix composites become interesting for use as constructional and functional materials, if the property profile of conventional materials either does not reach the increase standards of specific demands, or is the solution of the problem (Tolga Tavsanoglu, 2014).

There were many advantages of MMCs including a higher specific modulus, good properties at elevated temperature and better wear resistance. There are also the improvement in thermal shock resistance and corrosion resistance. Because of all these aspects, MMCs are under consideration for a wide application in aerospace industry. In general, MMCs consists of three main types which are continuous fibre, discontinuously fibre reinforced and particulate reinforced (Smith 2011).

Table 2.1: Mechanical properties of metal matrix composite materials

	Tensile Strength MPa	Elastic Modulus GPa	Strain to failure %
Continuous fibre MMCs:			
Al 2024-T6 (45% B) (axial)	1458	220	0.810
Al 6061-T6 (51% B) (axial)	1417	231	0.735
Al 6061-T6 (47% SiC) (axial)	1462	204	0.890
Discontinuous fibre MMCs:			
Al 2124-T6 (20% SiC)	650	127	2.4
Al 6061-T6 (20% SiC)	480	115	5.0
Particulate MMCs:			
Al 2124 (20% SiC)	552	103	7.0
Al 6061 (20% SiC)	496	103	5.5
No reinforcement:			
Al 2124-F	455	71	19
Al 6061-F	310	68.9	12

Source: Smith (2011)

i. Continuous Fibre Reinforced MMCs

As a group in fibre reinforced composite, continuous fibre composite tend to be more expensive compared to the discontinuous fibre composite but having a significantly improved performance. Raw continuous fibre composite may come in many forms such as rod, woven mats, tapes and pultruded. The first development of MMCs was aluminium alloy matrix with the boron fibre. The other continuous fibre composite which are usually used are graphite, alumina, silicon carbide and tungsten.

Silicon carbide is one of example of the brittle fibre MMCs. The strength is controlled by the fractured of fibre. While the tungsten fibre reinforced copper alloy is an example of ductile fibre MMCs which also yield and plastically deform along with the matrix (Mallick, 2007).

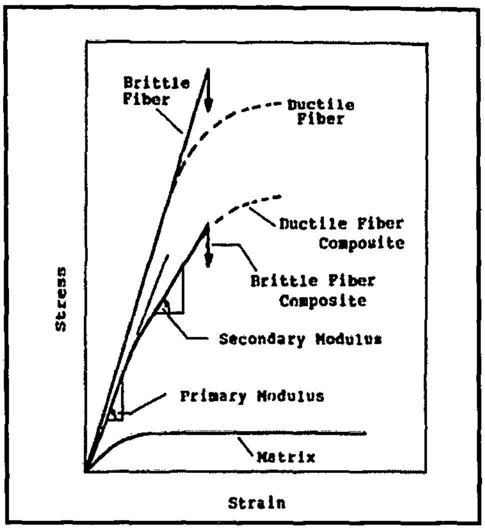

Figure 2.2: Schematic of the unidirectional continuous fiber reinforced MMCs

Source: Mallick (2007)

ii. Discontinuously Reinforced MMCs and Particulate Reinforced MMCs

Powder metallurgy is the main process of producing a discontinuous-fiber reinforced MMCs and lastly will undergo the impregnation and infiltration processes. During the powder metallurgy process, there are about 1 to 3 μm diameters and 50 to 200 μm long of needlelike silicon carbide whisker are mixed with the metal powders. After that, there were consolidation process using hot pressing method and lastly is extruded into a shape. Even though the higher strength and stiffness will be achieved, those processes are most costly.

Particulate reinforced of MMCs are more low in cost metal alloy MMCs built by suing irregular-shaped particles of silicon carbide or alumina about 3 to 200 μm diameter in range. This particulate can be produce by mix with the molten metal alloy and built it into remelt ingots or other method which is extruded billets for further fabrication.

Both materials having their engineering benefit of better dimensional stability, high strength and stiffness compared to the unreinforced metal alloys. The current applications for both materials include automobile parts and sporting equipment (Smith, 2011).

2.2.2 Ceramic Matrix Composites (CMCs)

The ceramic matrix composite, CMCs are quite important because of their corrosive environments and high resistance temperatures. Ceramics are actually can resist high temperature, strong and stiff but lack of toughness. Fibres usually used are carbon and aluminium oxide. The ceramic matrix composite have the high mechanical strength even at high temperature. There are also having a high stiffness, toughness, and thermal stability but having a low density.

There are many applications of CMCs such as an automotive engine components, cutting tools, pressure vessel and structural components. Again, there are three main types of CMCs which are continuous fibre, discontinuously fibre and particulate reinforced (Kalpakjian and Schmid, 2010).

i. Continuous-Fibre Reinforced CMCs

Silicon carbide and aluminium oxide are the two kind continuous fibre usually used. During the process to cast the composite, silicon fibre were woven to produce into a mat form. After that, the chemical vapour deposition process has been used to reproduce that fibre into a form of a fibrous mat (Smith, 2004).

ii. Discontinuous (Whisker) and Particulate Reinforced CMCs

The use of discontinuous reinforcement like particulates, platelets and most fibres can also improve certain properties and can be used to produce valuable materials. The main advantage of these systems is a massive increase in fracture toughness over unreinforced matrix. For example, SiC whisker is added to alumina which can make the fracture toughness of alumina increase (Warren, 1992).

There are three main toughening mechanisms which are believed to be tough the ceramic matrix composites. These mechanisms are crack deflection, crack bridging and fibre pullout.

2.2.3 Polymer Matrix Composites (PMCs)

Differs from ceramic matrix composite, the reinforcement in PMCs provides strength and stiffness that are lacking in the matrix. PMCs are very popular because of the low cost and also having simple fabrication methods. Reinforcement of polymers by strong fibre network permits fabrication and operation of polymer matrix composite characterized a very good in tensile strength and stiffness. There are also have excellent condition in corrosion resistance and having a low cost.

Polymer matrix composites are used for manufacturing such as to produce, boat bodies, canoes, automotive parts, sport goods and others. PMCs are split into two groups which are reinforced plastics and advanced composites. The different between two categories is based on their mechanical properties (Reginald, 1985).

i. Reinforced Plastics

The reinforced plastic is relatively inexpensive and usually consists of polyester resin reinforced with the low stiffness glass fibre. This type of composite has been used in for 30-40 years in many applications such as automobile panel, pipe, sporting goods and boat hulls (Reginald, 1985).

ii. Advanced Composites

This advanced composite had been used about 15 years ago which started by aerospace industry. A composite consists if fibre and matrix that yields the massive strength and stiffness. Usually advanced composites are more expensive and typically contain a large percentage of continuous fibre such as graphite, high stiffness glass (S-glass) and aramid (Reginald, 1985). There are 5 basic components of polymer matrix composites which are matrix, thermoses, thermoplastics, reinforcement and interphase.

Table 2.2: Comparison of three polymer categories

Behaviour	General Structure	Example
Thermoplastic	Flexible linear chain (straight or branched)	Polyethylene
Thermosetting	Rigid in three-dimensional network (chain either linear or branched)	Polyurethanes
Elastomers	Thermoplastics and lightly cross-linked thermosets consist of the spring like molecules	Natural rubber

Sources: Askeland et al. (2010)

2.3 POWDER METALLURGY

Powder metallurgy is a traditional process with production of metal powder to make a useful product. Nowadays, the powder metallurgy process is increasingly used to produce exceptional properties that are required in aerospace electronic and nuclear industry. However, in automobile industry the powder metallurgy process have been used as a major consumer. This process can eliminate or minimise the machining for finishing process and it suitable for high volume production of some components or parts. Addition, it offers economy, saving in raw material and energy along the mass production (Ramakrishnan, 1980).

Powder metallurgy process have several benefits over wrought or cast techniques in producing new products such as composite materials, refractory metals and special high duty alloys (Selvalumar et, al., 2005). In powder metallurgy method, the raw powders can be either elemental or prealloyed. Nonetheless, it is difficult to take advantage for both these requirements because they are prone to cause a non-homogenous distribution (S.Das et, al., 2010).

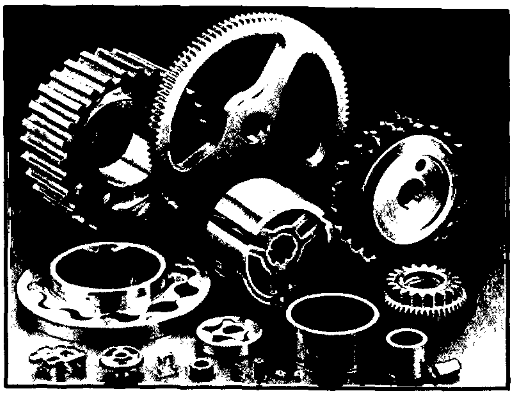

Figure 2.3: Products of powder metallurgy process

Source: China-mech Component Co., ltd

There are few commonly used metal in powder metallurgy which is iron, copper, aluminium, nickel, titanium and refractory metals. There are typical powder metallurgy process consists of five main sequences which is powder production, blending, compaction, sintering and lastly finishing operation (Kalpakjian and Schmid, 2010).

Basically, through conventional powder metallurgy production, after the powders have been produced, the sequence involves of three main steps. Firstly, blending and mixing the powder and then continued with compaction. Through compaction, powders are pressed in a die into desired part shape. The last step of powder metallurgy method is sintering process, which involve heating to some temperature which is below the melting point cause solid state bonding of the particles and strengthening the part (Sanjay Sharma and Dipendra Singh, 2013).

This technique has so many advantages such as can guarantee the correctness of the material composition ratio and uniformity. It also suitable for the production of the same shape and quantity of the products for example, gear. The high cost of processing products, manufactured by powder metallurgy method can greatly reduce the production cost.

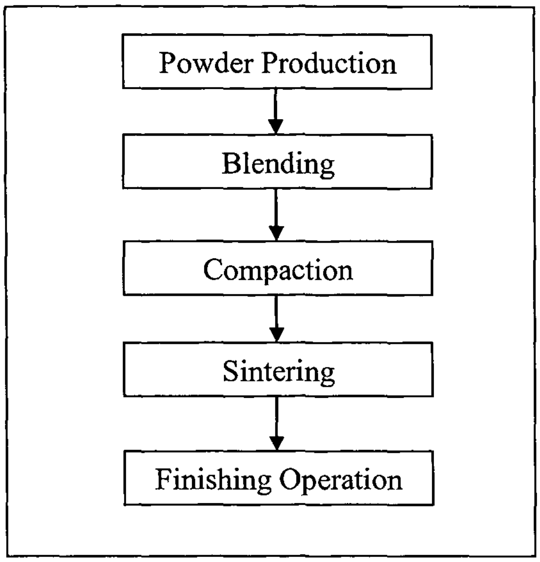

Figure 2.4: A flow chart of powder metallurgy process

i. Powder Production

The choice of powder production process is based on the requirements of the end product. There are various techniques of producing metal powder and most of them can be produced by more than a technique. The microstructure, chemical purity, surface properties size and shape of particles depend on the particular method used.

This is quite important because they were affect the permeability and flow during compaction and sintering operation. The particles sizes produced range from 0.1 to 1000µm. the example of method for powder production is atomization, comminution, mechanical alloying and electrolytic deposition (Kalpakjian and Schmid, 2010).

ii. Blending

After complete the production of metal powder, the powder must be in homogenous structure. The powder mixing is carried out to avoid contamination and deterioration. Most of metal powders are mixed with other binder to develop sufficient