THE INFLUENCE OF SLAG AND PSAC ON THE WEAR RESISTANCE OF COMPOSITE ALUMINIUM

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ABSTRACT

This research involves the fabrication of aluminum composite by using Palm Shell Activated Carbon (PSAC) and Boiler Slag as reinforcements. The method used is powder metallurgy. For aluminum composite fabrication process, set compaction pressure of 200 MPa and sintering temperature was at 500°c and for 2 hours. Composite samples produced from pure aluminum as a matrix and PSAC and Boiler Slag as reinforcement. All samples were set at 80% pure aluminum while the ratio of reinforcements is as follows; sample A, 0% PSAC, 0% Boiler Slag; sample B, 0% PSAC, 20% Boiler Slag; sample C, 2% PSAC, 18% Boiler Slag; sample D, 4% PSAC, 16% Boiler Slag; sample E, 6% PSAC, 145 Boiler Slag; sample F, 8% PSAC, 12% boiler Slag and sample G,10% PSAC, 10% Boiler Slag. These composites were tested using wear test (ASTM G99-95, 2000). The composites were also tested for hardness, density, porosity and microscopic test. Based on the wear test, is found that PSAC and Boiler Slag enforcement influence the wear rate of the aluminum composite produced. For the best wear resistance, composite composition is 80% Al, 2% PSAC and 18% Boiler Slag. Based on the observation of the microstructure of aluminum composite produced, is found PSAC and Boiler Slag particles still in original condition. This indicates it is appropriate to provide aluminum composite reinforcements. Based on the porosity test, is found PSAC and Boiler Slag enforcement influence the rate of porosity aluminum composite produced. Density test shows the contents of PSAC and Boiler Slag enforcement influence the density of the composite. Hardness test showed the contents of PSAC and Boiler Slag enforcement influence the hardness of the composite. Aluminum composite containing 80% Al, 2 PSAC% and 18% Slag is the most hard. Aluminum composite produced potential as automotive and motorcycle components.

Keyword; Aluminum Composite, Palm Shell Activated Carbon (PSAC), Boiler Slag, Wear Resistance.

ABSTRAK

Penyelidikan ini melibatkan fabrikasi aluminium komposit menggunakan *Palm Shell Activated Carbon* (PSAC) *and Boiler Slag* sebagai bahan penguat. Kaedah fabrikasi yang digunakan adalah metalurgi serbuk. Untuk proses fabrikasi tekanan mampatan ditetapkan pada 200 Mpa dan suhu sinteran 500°c selama 2 jam. Setiap sampel ditetap 80% aluminium tulen manakala nisbah bahan penguat adalah seperti berikut; sampel A, 0% PSAC, 0% *Boiler Slag*; sampel B, 0% PSAC, 20% *Boiler Slag*; sampel C, 2% PSAC, 18% *Boiler Slag*; sampel D, 4% PSAC, 16% *Boiler Slag*; sampel E, 6% PSAC, 14% *Boiler Slag*; sampel F, 8% PSAC, 12% *boiler Slag* and sampel G,10% PSAC, 10% *Boiler Slag*. Komposit ini dibuat ujian haus mengunakan *wear test* (ASTM G99-95, 2000). Komposit ini juga menjani ujian kekerasan, ketumpatan, keliangan dan ujian mikroskopik. Berdasarkan ujian kehausan didapi PSAC dan *Boiler Slag* mempengaruhi kadar kehausan aluminium komposit yang dihasilkan. Untuk rintangan haus yang terbaik, komposisi komposit ialah 80% Al, 2% PSAC dan 18% *Boiler Slag*. Berdarsarkan pemerhatian mirostruktur didapati PSAC dan Boiler Slag masih berada dalam keadaan asal. Ini menunjukkan ia sesuai dijadikan bahan penguat aluminium komposit. Ujian keliangan juga menunjukkan bahan penguat PSAC dan *Boiler Slag* mempengaruhi kadar keliangan aluminium komposit yang dihasilkan. Ujian ketumpatan menunjukkan kandungan penguat PSAC dan Boiler Slag mempengaruhi ketumpatan komposit. Ujian kekerasan menunjukkan kandungan bahan penguat PSAC dan *Boiler Slag* mempengaruhi kekerasan komposit. Aluminium komposit yang mengandungi 80% Al, 2% PSAC and 18% *Slag* adalah yang paling keras. Aluminium Komposit yang dihasilkan berpotensi untuk dijadikan komponen automotif dan motosikal.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The two largest producer countries of palm oil in the world are Malaysia and Indonesia. In Malaysia, oil palm shells containing high carbonaceous materials are generated in large quantity as a major by-product of the oil palm milling industry. Oil palm shells are usually burned as a low-value energy resource or discarded in the field, both of which are unfavorable to the environment. Due to high carbonaceous materials, oil palm shells are used as the precursor in the production preparation of activated carbon.

Malaysia is a country of study composite materials. This study is in the industry is trying to create a new composite with existing materials. Reinforcements used are slag and Palm Shell Activated Carbon (PSAC). The composite produced using powder metallurgy method. These composites were tested using wear test (ASTM G99-95, 2000). The composites were also tested hardness, density, porosity and microscope test. Significance of this research is as follows:

I. To evaluate whether the slag and PSAC can be used as reinforcements or not.
II. Finding benefits for waste boiler (slag) and PSAC as composite reinforcements.

1.2 Problem Statement

The problem is trying to overcome to use industrial wastes as composite reinforcements. For example before this Slag and PSAC is waste oil palm industry. Waste such as slag has improved palm oil mill operating costs. The management of the palm oil industry had to bear the cost of disposing of waste slag. Besides it was to study the use of slag and PSAC as reinforcements in composite aluminum.

1.3 Objective

Every research has identified several objectives to be achieved. There are three objectives to be achieved in this research. The objectives are as follows;

I. Determine the influence of PSAC and slag content on the wear properties.
II. Determine the characteristic of the composite.
III. Identify the best composition aluminum composite.

1.4 Scope

The scope of the research is based on the fabrication of aluminum composite by using Palm Shell Activated Carbon (PSAC) and Boiler Slag as reinforcements. The method used is powder metallurgy. For aluminum composite fabrication process, set compaction pressure of 200 MPa and sintering temperature was at 500°c and for 2 hours. Composite samples produced from pure aluminum as a matrix and PSAC and Boiler Slag as reinforcement. These composites were tested based on wear test standard ASTM G99-95. Table 1.1 shows the standard ASTM G99-95.

Table 1.1: The Standard of ASTM G99-95

scope	**matter**
Pure aluminum	basic material
PSAC and SLAG	reinforcements
125 µm	size of the reinforcements
powder metallurgy	fabrication techniques
200 Mpa	compaction pressure
500°C	sintering temperature
2 hours	sintering time
Pin on abrasive disc	wear test methods
100 m	distance slides
100 mm	diameter of abrasive disc
150 rpm	disk rotation speed
11 N	loads applied

1.5 Research Significance

Significance this research is to produce a new composite aluminum. Aluminum composite produced potential as automotive and motorcycle components. For the automotive industry it has the potential for use as disc brakes. For the motorcycle industry it has the potential for use as a drum brakes for small motorcycle.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There are many situations in engineering, that none of the single material can fulfill the design requirements and specific applications. The developments of products technology now require the unique material properties. It cannot be fulfilled by conventional metal alloys, ceramic and polymer materials. For example, in the aerospace industry an engineer looking lightweight materials, strong, rigid, good abrasion resistance and able to withstand the impact.

The term “composite” broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix), and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of the boundaries (interfaces) between different constituents. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composites. In addition there are some reports to indicate the emergence of interring metallic-matrix and carbon-matrix composites. This review is concerned with metal matrix composites and more specifically on the aluminum matrix composites (AMCs). In AMCs one of the constituent is aluminum/aluminum alloy, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminum/aluminum alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al2O3.[1] Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction. The major advantages of AMCs compared to unreinforced materials are as follows:

I. Greater strength
II. Improved stiffness
III. Reduced density(weight)
IV. Improved high temperature properties
V. Controlled thermal expansion coefficient
VI. Thermal/heat management
VII. Enhanced and tailored electrical performance
VIII. Improved abrasion and wear resistance
IX. Control of mass (especially in reciprocating applications)
X. Improved damping capabilities.

Aluminum-based materials studied seriously to replace iron-based materials in internal combustion engines. Based on research, one of the main driving force for the development of an aluminum matrix composite technology with ceramic particles are noted from the results of the composite have the high wear resistance and therefore the potential for a number of materials tribological applications.

Applications commonly practiced in the automotive industry is the piston, cylinder block and disk break. The use of aluminum composite can improve the performance of a vehicle as it is lighter than steel.

2.2 Aluminum Composite

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual component used alone. In contrast to metallic alloys, each material retains its separate chemical, physical and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness with bulk materials, allowing for a weight reduction in the finished part.[2]

Researchers at Delft University of Technology have created aluminum composite material that is stronger than carbon fiber, costs less to manufacture, weighs 20% less and is immune to metal fatigue. It is being billed as a material that could revolutionize the airline industries, saving $100 billion worldwide.

These advantages can be quantified for better appreciation. For example, elastic modulus of pure aluminum can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol.% continuous aluminum fiber. On the other hand incorporation of 60 vol% alumina fibre in pure aluminum leads to decrease in the coefficient of expansion from 24 ppm/°C to 7 ppm/°C. Similarly it is possible to process Al-9% Si-20 vol% SiCp composites having wear resistance equivalent or better than that of grey cast iron.[3] All these examples illustrate that it is possible to alter several technological properties of aluminum/aluminum alloy by more than two– three orders of magnitude by incorporating appropriate reinforcement in suitable volume fraction.

AMC material systems offer superior combination of properties (profile of properties) in such a manner that today no existing monolithic material can rival. Over the years, AMCs have been tried and used in numerous structural, non-structural and functional applications in different engineering sectors. Driving force for the utilization of AMCs in these sectors include performance, economic and environmental benefits. The key benefits of AMCs in transportation sector are lower fuel consumption, less noise and lower airborne emissions. With increasing stringent environmental regulations and emphasis on improved fuel economy, use of AMCs in transport sector will be inevitable and desirable in the coming years.

2.3 Reinforcement

The reinforcement is usually a fiber or a particulate. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical, platelets, or any other regular or irregular geometry.[4] Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 Volume percent) due to processing difficulties and brittleness.[2] A fiber has a length that is much greater than its diameter. The length-to-diameter (*l*/*d*) ratio is known as the *aspect ratio* and can vary greatly. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratios. Continuous-fiber composites normally have a preferred orientation, while discontinuous fibers generally have a random orientation. Examples of continuous reinforcements include unidirectional, woven cloth, and helical winding.

2.4 Matrix

The continuous phase is the matrix, which is a polymer, metal, or ceramic. Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility, and ceramics have high strength and stiffness but are brittle. The matrix (continuous phase) performs several critical functions, including maintaining the fibers in the proper orientation and spacing and protecting them from abrasion and the environment. In polymer and metal matrix composites that form a strong bond between the fiber and the matrix, the matrix transmits loads from the matrix to the fibers through shear loading at the interface. In ceramic matrix composites, the objective is often to increase the toughness rather than the strength and stiffness; therefore, a low interfacial strength bond is desirable.

2.5 Palm Shell Activated Carbon (PSAC)

Activated carbon is a crude material from graphite. One of the applications of this substance is as pencil lead. Activated carbon differs from graphite by having the random imperfect structure, which is highly porous over a broad range of pore size from visible cracks and crevices to molecular dimensions. The graphite structure gives the carbon a very large surface area, which allows the carbon to adsorb a wide range of compounds.

Activated carbon has the strongest physical adsorption forces of the highest volume of adsorbing porosity of any material known to mankind. It is a black, solid substance resembling granular or powdered charcoal and extremely porous with a very large surface area. Its surface area can reach up to more than 1000 m_2/g. In other words, five grams of activated carbon can have the surface area of football field. [5] There are three main forms of activated carbon:

1. Granular Activated Carbon (GAC)

   - Irregular shaped particles sizes ranging from 0.2 to 5mm. This type of activated carbon is used in both liquid and gas phase applications.

2. Powder Activated Carbon (PAC)

   - Pulverized carbon with a size predominantly less than 0.18 mm (US mess 80). These are mainly used in liquid phase applications and for flue gas treatment.

3. Pellet Activated Carbon

   - Extruded and cylindrical shaped with diameters from 0.8 to 5mm. They are mainly used for gas phase applications because of their low pressure drop, high mechanical strength and low dust content.

Activated carbon consists mainly of carbon (87 to 97%) and other elements such as hydrogen, oxygen, sulfur and nitrogen. Various compounds are also present either originating from the material or generated during its preparation. Activated carbon also can adsorb various substances both from gas and liquid phases. This ability justifies it as an adsorbent. [6]

Scanning electron macrographs for the external morphology of the activated carbon at the pyrolysis temperature of 500oC are displayed in Figure 1. It can be seen that the external surface of activated carbon is full of cavities.

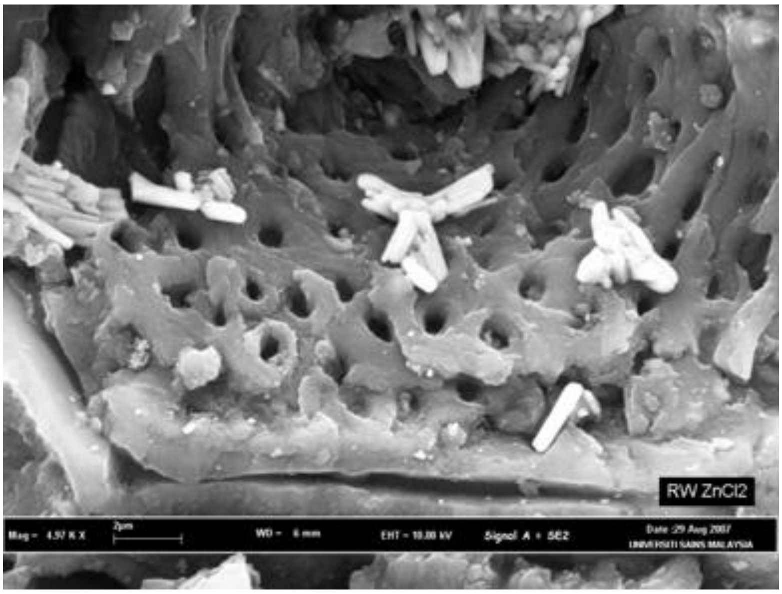


Figure 2.1: Scanning Electron Macrographs for The External Morphology Of The Activated Carbon At The Pyrolysis Temperature of 500°c.

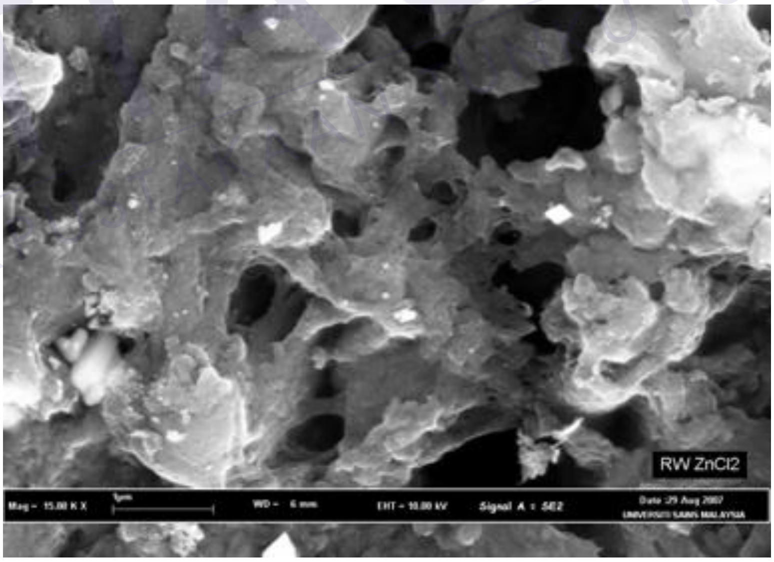


Figure 2.2: Structural Morphology of Activated Carbon Prepared By Chemical Activation With Zncl2 At 500oc. (A) Magnitude Of 4980x; (B) Magnitude of 15000x.

Palm shells share the same characteristics as its other sibling, coconut shells. They both possess a highly complex pore structure and fiber matrix, making it the raw material of choice for the production of premium activated carbon. No other type of activated carbon comes close in terms of high iodine values and superior hardness.

As a raw material for fuel briquettes, palm shells offer the same calorific characteristics as coconut shells. Palm shell charcoal is characterized with high energy content that is released slowly during combustion owing to its complex fiber matrix structure. Its smaller shell size makes it easier to carbonize for mass production, and its resulting palm shell charcoal can be pressed into a heat efficient biofuel briquette.

Our raw material is derived from tens of thousands of hectares of oil palm estate. This ensures a constant stream of palm shells that are of consistent quality, leading to a consistent and growing production of palm charcoal to feed our biofuel briquettes and activated carbon needs.

2.6 Slag

Slag is a partially vitreous by-product of the process of smelting ore, which separates the desired metal fraction from the unwanted fraction. Slag is usually a mixture of metal oxides and silicon dioxide. However, slags can contain metal sulfides (see also matte) and metal atoms in the elemental form. While slags are generally used to remove waste in metal smelting, they can also serve other purposes, such as assisting in the temperature control of the smelting, and minimizing any re-oxidation of the final liquid metal product before the molten metal is removed from the furnace and used to make solid metal.

2.7 Boiler Slag

Boiler slag is a by-product produced from a wet-bottom boiler, a special type of boiler designed to keep bottom ash in a molten state before it is removed. These types of boilers (slag-tap and cyclone boilers) are much more compact than pulverized coal boilers used by most large utility generating stations. They can burn a wide range of fuels and generate a higher proportion of bottom ash than fly ash (50 to 80% bottom ash vs. 15 to 20% bottom ash for pulverized coal boilers). These are some of the reasons they are typically used by industrial manufacturing plants and smaller utilities.

With wet-bottom boilers, the molten ash is withdrawn from the boiler and allowed to flow into quenching water. The rapid cooling of the slag causes it to immediately crystallize into a black, dense, fine-grained glassy mass that fractures into angular particles, which can be crushed and screened to the appropriate sizes for several uses.

Figure 2.3: Boiler Slag

Figure 2.4: Boiler Slag 'Needles' as viewed via a microscope

Since boiler slag is angular, dense and hard, it is often used as a wear-resistant component in surface coatings of asphalt in road paving. Finer-sized boiler slag can be used as blasting grit and is commonly used for coating roofing shingles. Other uses include raw material for the manufacture of cement and in colder climates, it is spread onto icy roads for traction control.

2.8 Wear

Wear is corrosion material from a solid surface by the action of another surface. This is related to surface interactions and more specifically the removal of material from the surface as a result of mechanical action. Wear occurs when two surfaces rub against each other with each other. Wear is defined as material loss that occurs when two surfaces rub each other.

According to ASTM G40 standard wear is defined as damage to a solid surface, generally involving progressive loss in the material, due to relative motion between the two surfaces and materials that come in contact.

2.9 Tribocorrosion

Tribocorrosion is a material degradation process due to the combined effect of corrosion and wear. The name tribocorrosion expresses the underlying disciplines of tribology and corrosion.[7] Tribology is concerned with the study of friction, lubrication and wear (its name comes from the Greek "tribo" meaning to rub) and corrosion is concerned with the chemical and electrochemical interactions between a material, normally a metal, and its environment. As a field of research tribocorrosion is relatively new, but tribocorrosion phenomena have been around ever since machines and installations are being used.

Wear is a mechanical material degradation process occurring on rubbing or impacting surfaces, while corrosion involves chemical or electrochemical reactions of the material. Corrosion may accelerate wear and wear may accelerate corrosion. One then speaks of corrosion accelerated wear or wears accelerated corrosion. Both these phenomena, as well as fretting corrosion (which results from small amplitude oscillations between contacting surfaces) fall into the broader category of tribocorrosion. Erosion-corrosion is another tribocorrosion phenomenon involving mechanical and chemical effects: impacting particles or fluids erode a solid surface by abrasion, chipping or fatigue while simultaneously the surface corrodes.

2.10 Types of Wear Mechanisms

Wear mechanism of destruction is due to the frictional force between the two materials in contact. Corrosion is the destructive effect of the reaction mechanism of materials with environmental elements. Classification of aluminum composite wear depends on the wear mechanism itself. Type of wear in the limelight in aluminum composite is abrasion wear and adhesion wear.

For corrosion, the classification depends on the environmental conditions of wet corrosion or dry corrosion. Wet corrosion refers to corrosion that occurs in moist or watery conditions. The dry corrosion refers to high temperature corrosion. Corrosion studies often get attention researcher is wet corrosion because wet corrosion is often the case.

A systematic study on metal wear has been conducted in the past few decades and some wear phenomena have determinant aspects can be characterized in detail. Four major wear mechanisms were identified, namely; adhesive wear theory, abrasive wears theory, surface fatigue wear, and erosive wear.

2.10.1 Adhesive wear

Adhesive wear can be found between surfaces during frictional contact and generally refers to unwanted displacement and attachment of wear debris and material compounds from one surface to another. Two separate mechanisms operate between the surfaces. “Friccohesity” defines actual changes in cohesive forces and their reproduction in form of kinetic or frictional forces in liquid when the clustering of the Nano-particles scatter in medium for making smaller cluster or aggregates of different manometer levels.

I. Adhesive wear are caused by relative motion, "direct contact" and plastic deformation which create wear debris and material transfer from one surface to another.
II. Cohesive adhesive forces, holds two surfaces together even though they are separated by a measurable distance, with or without any actual transfer of material.

The above description and distinction between "Adhesive wear" and its Counterpart "cohesive adhesive forces" are quite common. Usually cohesive surface forces and adhesive energy potentials between surfaces are examined as a special field in physics departments. The adhesive wear and material transfer due to direct contact and plastic deformation are examined in engineering science and in industrial research.

Two aligned surfaces may always cause material transfer and due to overlaps and symbiotic relations between relative motional “wear” and “chemical” cohesive attraction, the wear-categorization have been a source for discussion. Consequently, the definitions and nomenclature must evolve with the latest science and empiric observations.

Generally, adhesive wear occurs when two bodies slide over or are pressed into each other, which promote material transfer. This can be described as plastic deformation of very small fragments within the surface layers. The asperities or microscopic high points or surface roughness found on each surface, define the severity on how fragments of oxides are pulled off and adds to the other surface, partly due to strong adhesive forces between atoms[8] but also due to accumulation of energy in the plastic zone between the asperities during relative motion.

The outcome can be a growing roughening and creation of protrusions (i.e., lumps) above the original surface, in industrial manufacturing referred to as galling, which eventually breaches the oxidized surface layer and connects to the underlying bulk material which enhance the possibility for a stronger adhesion and plastic flow around the lump.

The geometry and the nominal sliding velocity of the lump defines how the flowing material will be transported and accelerated around the lump which is critical to define contact pressure and developed temperature during sliding. The mathematical function for acceleration of flowing material is thereby defined by the lumps surface contour. It's clear, given these prerequisites, that contact pressure and developed temperature is highly dependent on the lumps geometry.

Flow of material exhibits an increase in energy density, because initial phase transformation and displacement of material demand acceleration of material and high pressure. Low pressure is not compatible with plastic flow; only after deceleration may the flowing material be exposed to low pressure and quickly cooled. In other words, you can't deform a solid material using direct contact without applying a high pressure and somewhere along the process must acceleration and deceleration take place, i.e., high pressure must be applied on all sides of the deformed material. Flowing material will immediately exhibit energy loss and reduced ability to flow due to phase transformation, if ejected from high pressure into low pressure. This ability withholds the high pressure and energy density in the contact zone and decreases the amount of energy or friction force needed for further advancement when the sliding continues and partly explain the difference between the static and sliding coefficient of friction (**μ**) if the main fracture mechanisms are equal to the previous.

Adhesive wear is a common fault factor in industrial applications such as sheet metal forming (SMF) and commonly encountered in conjunction with lubricant failures and are often referred to as welding wear or galling due to the exhibited surface characteristics, phase transition and plastic flow followed by cooling. The type of mechanism and the amplitude of surface attraction vary between different materials but are amplified by an increase in the density of "surface energy". Most solids will adhere on contact to some extent. However, oxidation films, lubricants and contaminants naturally occurring generally suppress adhesion.[9] And spontaneous exothermic chemical reactions between surfaces generally produce a substance with low energy status in the absorbed species.

2.10.2 Abrasive Wear

Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM International (formerly American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface.

Abrasive wear is commonly classified according to the type of contact and the contact environment. The type of contact determines the mode of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear. Two-body wear occurs when the grits or hard particles remove material from the opposite surface. The common analogy is that of material being removed or displaced by a cutting or plowing operation. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface.

The contact environment determines whether the wear is classified as open or closed. An open contact environment occurs when the surfaces are sufficiently displaced to be independent of one another. Deep 'groove' like surface indicates abrasive wear over cast iron (yellow arrow indicate sliding direction)

There are a number of factors which influence abrasive wear and hence the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is removed. Three commonly identified mechanisms of abrasive wear are:

Plowing, Cutting, Fragmentation.

Plowing occurs when material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridges adjacent to grooves, which may be removed by subsequent passage of abrasive particles. Cutting occurs when material is separated from the surface in the form of primary debris, or microchips, with little or no material displaced to the sides of the grooves. This mechanism closely resembles conventional machining. Fragmentation occurs when material is separated from a surface by a cutting process and the indenting abrasive causes localized fracture of the wear material. These cracks then freely propagate locally around the wear groove, resulting in additional material removal by palling. Abrasive wear can be measured as loss of mass by the Taber Abrasion Test according to ISO 9352 or ASTM D 1044.

2.10.3 Surface fatigue

Surface fatigue is a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. Fatigue wear is produced when the wear particles are detached by cyclic crack growth of micro cracks on the surface. These micro cracks are either superficial cracks or subsurface cracks.

2.10.4 Erosive Wear

Erosive wear can be described as an extremely short sliding motion and is executed within a short time interval. Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. It is a widely encountered mechanism in industry. A common example is the erosive wear associated with the movement of slurries through piping and pumping equipment.

The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, and impact velocity and impingement angle are primary factors along with the properties of the surface being eroded. The impingement angle is one of the most important factors and is widely recognized in literature. For ductile materials the maximum wear rate is found when the impingement angle is approximately 30°, whilst for non-ductile materials the maximum wear rate occurs when the impingement angle is normal to the surface.[10]

2.11 Wear Test

There are various methods of testing wear; table 2.1 shows some wear test standard methods. Some of the ASTM standards are shown below.

Table 2.1: Standard Tests From A Wide Range Of Organizations, Including AENOR, AFNOR, ANSI, ASTM, BSI, CEN, DIN, ISO, JIS And SAE Can Be Performed On The Taber Abraser.

ASTM C501-84	Standard Test Method for Relative Resistance to Wear of Unglazed Ceramic Tile by the Taber Abraser
ASTM C1353-08	Standard Test Method Using the Taber Abraser for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic
ASTM D1044-08	Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion
ASTM D3389-05	Standard Test Method for Coated Fabrics Abrasion Resistance (Rotary Platform Double-Head Abrader)
ASTM D3451-06	Standard Practices for Testing Polymeric Powders and Powder Coatings
ASTM D3730-03	Standard Guide for Testing High-Performance Interior Architectural Wall Coatings
ASTM D3884-09	Standard Guide for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double-Head Method)
ASTM D4060-07	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM D4685-07	Standard Test Method for Pile Fabric Abrasion
ASTM D4712-87	Standard Guide for Testing Industrial Water-Reducible Coatings
ASTM D5144-08	Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants
ASTM D5146-03	Standard Guide to Testing Solvent-Borne Architectural Coatings
ASTM D5324-03	Standard Guide for Testing Water-Borne Architectural Coatings
ASTM D6037-96	Standard Test Methods for Dry Abrasion Mar Resistance of High Gloss Coatings

ASTM D7255-06	Standard Test Method for Abrasion Resistance of Leather (Rotary Platform, Double-Head Method)
ASTM F362-91	Standard Test Method for Determining the Erasability of Inked Ribbons
ASTM F510-93	Standard Test Method for Resistance to Abrasion of Resilient Floor Coverings Using an Abrader with a Grit Feed Method
ASTM F1478-06	Standard Test Method for Determination of Abrasion Resistance of Images Produced from Copiers and Printers (Taber Method)
ASTM G195-08	Standard Guide for Conducting Wear Tests Using a Rotary Platform, Double-Head Abraser

2.11.1 Pin on disc

A pin on disc *tribometer* consists of a stationary "pin" under an applied load in contact with a rotating disc. The pin can have any shape to simulate a specific contact, but spherical tips are often used to simplify the contact geometry. Coefficient of friction is determined by the ratio of the frictional force to the loading force on the pin.

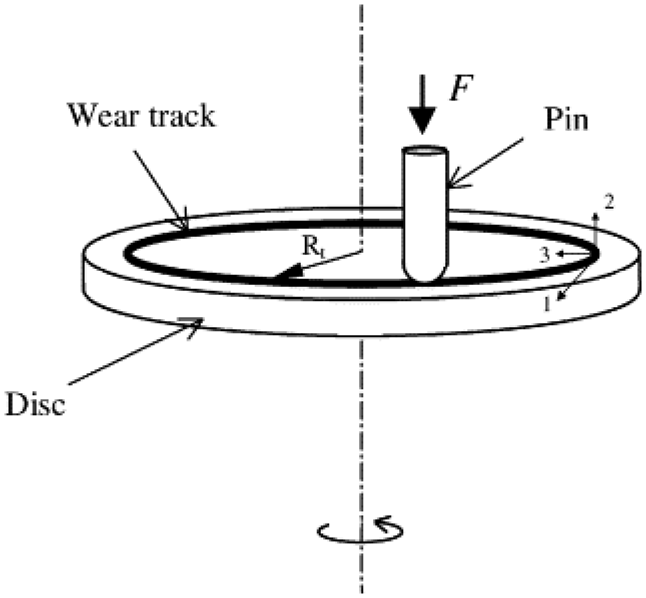


Figure 2.5: Pin On Disc Mechanism

2.12 Summary

Based on the literature review, aluminum composite was found have a better engineering properties than pure aluminum. The reinforcement produces the strength and stiffness to composite material. Boiler slag is a material that is suitable for enforcement because it is dense and hard. Its use as an enforcement can increase the wear resistance of aluminum composite.

PSAC also be added in the production of aluminum composite. PSAC will make aluminum composite materials have the porous character. These characters are also important in engineering element. It will make a material lighter and has a high friction.

The easiest method to implement wear test is a method of pin on disc base on ASTM GG99-95.

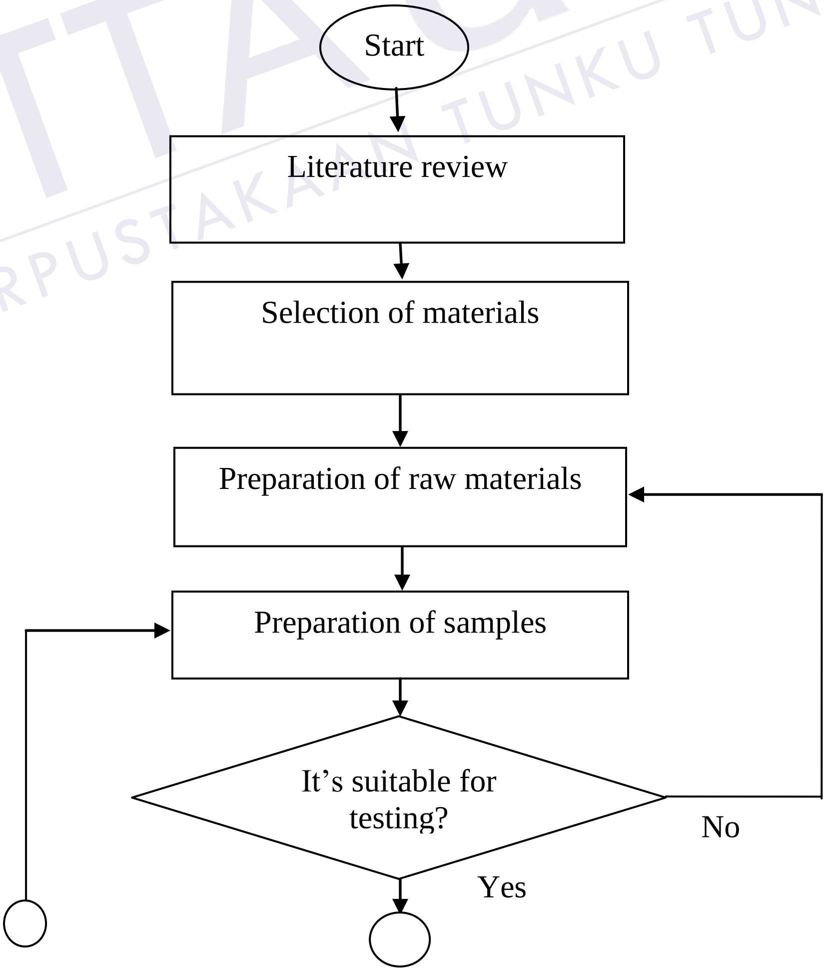
CHAPTER 3

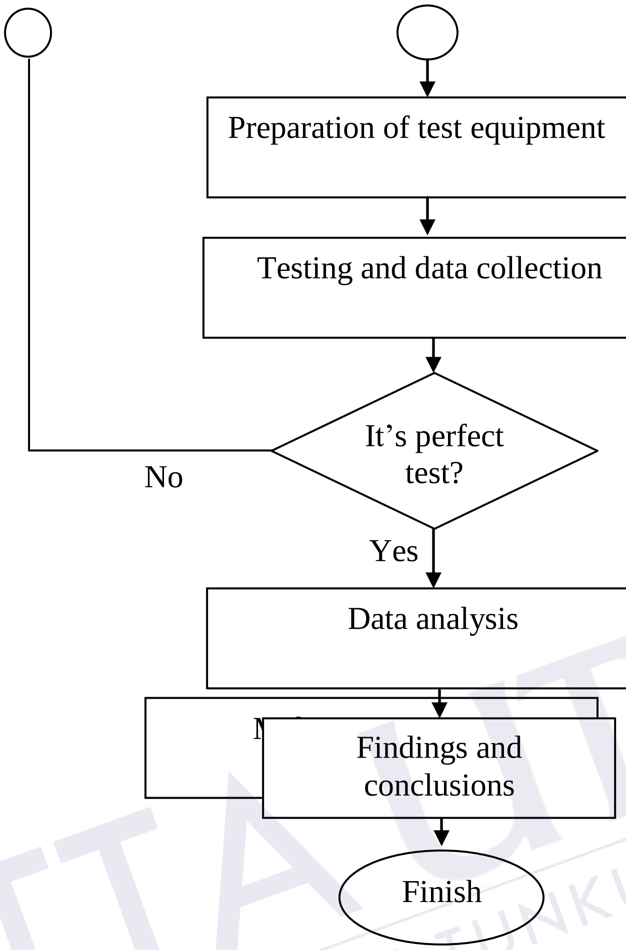
RESEARCH METHODOLOGY

3.1 Introduction

Research methodology begins with a literature review, selection of materials, preparation of raw materials, preparation of samples were, preparation of test equipment, make experiments, data collection, and data analysis. Chart 1 shows a flow chart of research methodology.

Chart 3.1: Flow Chart of Research Methodology.





3.2 Selection of Materials

Material selection is made based on the problem statement. The material selected for research was PSAC, pure aluminum, and slag. PSAC is the product of downstream palm oil industry. Boiler slag is a by-product produced from a wet-bottom boiler of palm oil mills.

3.3 Preparation of Raw Materials

Slag placed on iron plate and crushed using a hammer. Large chunks of slag will be smaller pieces. Smaller pieces then put in containers made from steel. Slag crushing process continues using the hammer in the containers. Slag powder is produced. Slag powder put in a blender to produce a finer powder. Slag powder was then filtered using a filter machine to obtain a uniform grain size of 125 microns. Produced slag powder is stored in containers and labeled. The same method is used to produce PSAC powder.

3.4 Preparation of Samples

Digital weighing scale used for the preparation of the experimental samples. Percentage of the mixture is based on the weight of the material. Each of the ingredients is weighed using a micro Balancer to get the exact percentage. Experiments were conducted discretion to determine the mixing ratio. Composite with more than 10% PSAC cannot be sintered. Table 3.1 shows the percentage of the mixture of enforcement. Figure 3.1 show the digital weighing scale.

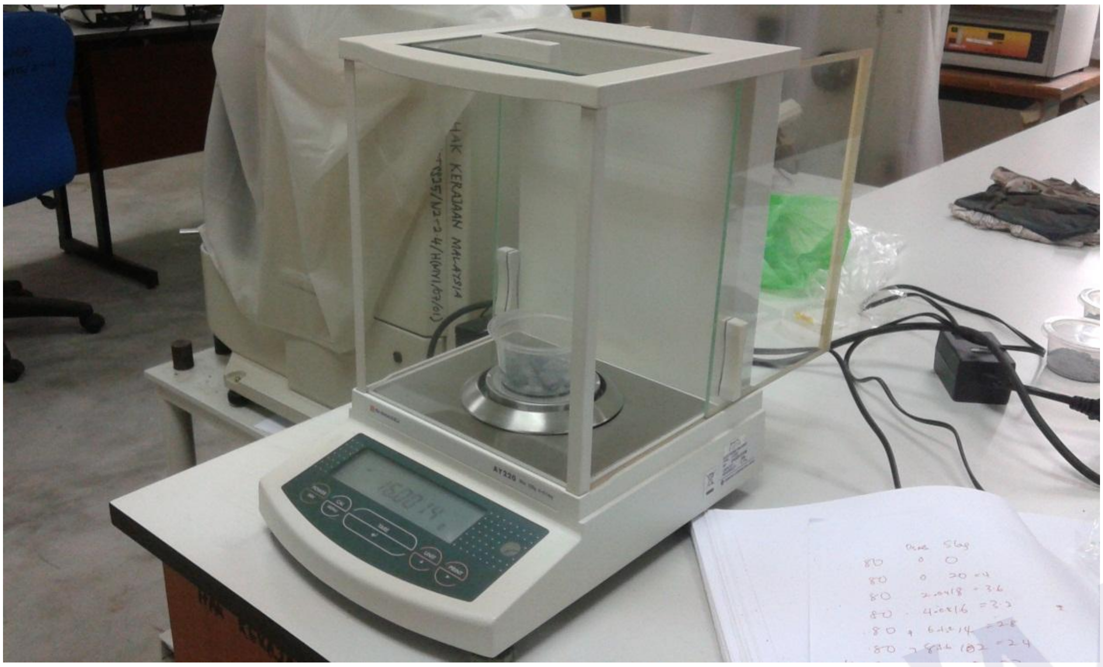


Figure 3.1: The Digital Weighing Scale

Table 3.1: Percentage of the Mixture of Enforcement

Composite	Aluminum %	PSAC %	Slag %
A	80	0	0
B	80	0	20
C	80	2	18
D	80	4	18
E	80	6	14
F	80	8	12
G	80	10	10

To ensure smooth mixture, the mixture added to a sealed container and turned on a lathe machine. Mixture is then inserted into a mold and compacted with the aid of a hydraulic press. Respite was temporary though, the resulting pin is removed from the mold. Keep pin produced in a closed container and label. Next clean the mold with cleaning liquid. All these steps are repeated for the other percentage of mix.

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