Faculty of Manufacturing Engineering

EFFECT OF GRAPHENE NANOPLATELETS ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINIUM MATRIX COMPOSITE

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Master in Manufacturing Engineering

(Advanced Materials and Processing Engineering)

2023

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A dissertation submitted in fulfilment of the requirement for the degree of Master in Manufacturing Engineering (Advanced Materials and Processing Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this dissertation entitled "Effect of Graphene Nanoplatelets on theMicrostructural and Mechanical Properties of Aluminium matrix composite" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ....

Name: Loga Varathan a/l Segar

Date: 17/8/2023

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality as a partial fulfilment of Master of Manufacturing Engineering (Advanced Materials and Processing Engineering).

Signature : ....

Supervisor Name: PM Ir. Ts. Dr. Mohd Shukor bin Salleh

Date: 19/8/23

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DEDICATION

This report is dedicated to my bellowed family, lecturers and friends, who taught me that the best kind of knowledge to have been that which is learned for its own sake. It is also dedicated to my father and mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ABSTRACT

In this study, an effort for improving the properties of aluminum matrix composites by adding the different concentration of graphene nanoplatelets. The improved composite can be used on specific application such as automobile and aviation field. Graphene is itself a material with exceptional mechanical, thermal as well as microstructural properties such as high strength, high electrical and thermal conductivity, chemical inertness features and linear dispersive electronic structure. Therefore, a graphene reinforced aluminum matrix composite with varying concentration is prepared using stir casting method. In this project, Al 360 Alloy is used as an aluminum matrix composite. The investigation of the mechanical and physical properties of graphene reinforced aluminum composite matrix is done using different experimental setup such as: XRD (X-ray diffraction), DSC (Differential Scanning Calorimetry) and UTM (Universal Tensile Machine). XRD is used to investigate the chemical properties of graphene reinforced aluminum matrix composite such as such as crystal structure, shape and size of graphene nanoplates in the composites. DSC is used to find out the thermal properties of the prepared matrix composite such as melting point, specific heat capacity, glass transition temperature. Similarly, UTM is used to determine the mechanical properties of the prepared composites of varying graphene compositions. UTM is used to apply 20 kN tensile load and measure the deformation and load information. The information obtained is useful for determine the mechanical properties such as Young's modulus, yield strength, and ultimate tensile strength of the material. The discussed experiments are carried on different concentrations of graphene on aluminum matrix composite due to which an optimal concentration of graphene that improves the properties and beneficial for specific application is found out. The tensile testing results of Graphene Nanoplatelet (GNP)-reinforced composite specimens are summarized. Specimens with different GNP concentrations (0.3%, 0.6%, and 0.9%) were evaluated for their elastic modulus, tensile strength, yield strength, modulus of resilience, modulus of toughness, and ductility. The results indicate that the concentration of GNP significantly influences the mechanical properties of the composites. Higher GNP concentrations generally lead to increased tensile strength and yield strength. However, the ductility of the composites decreases with higher GNP concentrations. These findings provide valuable insights for the optimization of GNP-reinforced composites and inform the design of advanced materials with improved mechanical characteristics.

ABSTRAK

Dalam kajian ini, satu usaha untuk menambah baik sifat komposit matriks aluminium dengan menambahkan kepekatan nanoplatelet graphene yang berbeza. Komposit yang dipertingkatkan boleh digunakan pada aplikasi tertentu seperti bidang automobil dan penerbangan. Graphene sendiri adalah bahan dengan sifat mekanikal, haba serta mikrostruktur yang luar biasa seperti kekuatan tinggi, kekonduksian elektrik dan haba yang tinggi, ciri-ciri lengai kimia dan struktur elektronik penyebaran linear. Oleh itu, komposit matriks aluminium bertetulang graphene dengan kepekatan yang berbeza-beza disediakan menggunakan kaedah tuangan kacau. Dalam projek ini, Al 360 Alloy digunakan sebagai komposit matriks aluminium. Penyiasatan sifat mekanikal dan fizikal bagi matriks komposit aluminium bertetulang graphene dilakukan menggunakan persediaan eksperimen yang berbeza seperti: XRD (pembelauan sinar-X), DSC (Kalorimetri Pengimbasan Berbeza) dan UTM (Mesin Tegangan Universal). XRD digunakan untuk menyiasat sifat kimia komposit matriks aluminium bertetulang graphene seperti seperti struktur kristal, bentuk dan saiz plat nano graphene dalam komposit. DSC digunakan untuk mengetahui sifat terma komposit matriks yang disediakan seperti takat lebur, muatan haba tentu, suhu peralihan kaca. Begitu juga, UTM digunakan untuk menentukan sifat mekanikal bagi komposit yang disediakan bagi komposisi graphene yang berbeza-beza. UTM digunakan untuk menggunakan beban tegangan 20 kN dan mengukur maklumat ubah bentuk dan beban. Maklumat yang diperolehi berguna untuk menentukan sifat mekanikal seperti modulus Young, kekuatan alah, dan kekuatan tegangan muktamad bahan. Eksperimen yang dibincangkan dijalankan pada kepekatan graphene yang berbeza pada komposit matriks aluminium kerana kepekatan optimum graphene yang meningkatkan sifat dan bermanfaat untuk aplikasi tertentu didapati. Keputusan ujian tegangan bagi spesimen komposit bertetulang Nanoplatelet Graphene (GNP) diringkaskan. Spesimen dengan kepekatan KNK yang berbeza (0.3%, 0.6%, dan 0.9%) dinilai untuk modulus keanjalan, kekuatan tegangan, kekuatan hasil, modulus keanjalan, modulus keliatan dan kemuluran. Keputusan menunjukkan bahawa kepekatan KNK secara signifikan mempengaruhi sifat mekanikal komposit. Kepekatan KNK yang lebih tinggi biasanya membawa kepada peningkatan kekuatan tegangan dan kekuatan hasil. Walau bagaimanapun, kemuluran komposit berkurangan dengan kepekatan KNK yang lebih tinggi. Penemuan ini memberikan pandangan berharga untuk pengoptimuman komposit bertetulang KNK dan memaklumkan reka bentuk bahan termaju dengan ciri mekanikal yang dipertingkatkan.

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ACKNOWLEDGEMENTS

First and foremost, I would like to express my greatest gratitude to my respected supervisor, Associate Professor Ir. Ts. Dr. Mohd Shukor bin Salleh for his humble guidance, patient, encouragement, enthusiasm, invaluable support and motivation throughout the whole completion of this project. This study would not be succeeded without his continuous support and precious time.

Secondly, I would like to drop my sincere appreciation to thank all my friends who have always motivated or even guided me in accomplishing this study either physically or mentally as well.

Last but not least, I would like to express my heartiest appreciation to my parents and family, who were always there when I needed the most. I had learned a lot, not just theoretically but also practically during the entire study.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
AMCs	Aluminum Matrix Composites
BNAs	Bulk Nanocrystalline aluminum Alloys
cc	Centimeter Cube
CNTs	Carbon Nanotubes
DSC	Differential Scanning calorimetry
GNFs	Graphene Nanoflakes
GNPs	Graphene Nanoplatelets
GNSs	Graphene Nanosheets
GO	Graphene Oxides
GPa	Giga Pascal
GPLs	Graphene Platelets
HIP	Hot Isostatic Pressing
MPa	Mega Pascal
TPa	Terra Pascal
XRD	X-ray Diffraction

Chapter 1

INTRODUCTION

1.0 Overview

The sp2-bonded carbon atoms in graphene form a flawless 2-D lattice with superior characteristics. Its fracture strength, which is measured in terms of 125 GPa, and Young's modulus, both of which reach astonishingly high values, both approach 1 TPa. A.A. Balandin et al. measured a suspended single-layer graphene's thermal conductivity to be extraordinarily high (5000 W m-1 K-1). demonstrating the superiority of graphene as a heat-management material. K.I. Bolotin et al. studied the mobility of its super charge-carrier (200,000 cm2 V-1 s-1). In order to be employed as fillers in metal-matrix composites, a variety of graphene forms have been researched and tested. Due to their shape, graphene nanoplatelets (GNPs) are among the greatest candidates for nanofillers in the creation of composites with an aluminum matrix (multiple graphene sheets with a stack-like morphology) (Sharma et al., 2019).

Because of its exceptional qualities, including as superior mechanical strength, high carrier mobility, high electrical and thermal conductivity, chemical inertness features, and the linear dispersive electronic structure, one atom thick graphene has garnered a lot of interest. Recent research on graphene has focused on its relationship to superconductivity. In superconducting graphene superconductor junctions, superconducting nano islands atop graphene, superconductor-graphene heterostructures, and other structures, graphene becomes super conductive via connecting with the twisted graphene beneath or by proximity effect (Torabi Parizi et al., 2019).

Due to its exceptional mechanical qualities, graphene might be regarded as the perfect reinforcement for the creation of composites. These qualities provide a greater possibility for research into them in the creation of metal matrix composites. Due to the widespread use of aluminum in the automotive and aerospace industries, aluminum-matrix composites are a significant solution to current and upcoming structural component design difficulties. To enhance the mechanical performance of the composites in this case, the reinforcing material utilized in their creation is crucial (Khan et al., 2021). The development of aluminum-matrix composites has shown a favorable impact on the mechanical behavior of the finished products when using nanometric reinforcing materials. This is the case with composites made of aluminum and matrix that have recently been reinforced with graphene and carbon nanotubes (CNTs). Graphene is a single sheet of graphite with exceptional electrical, thermal, and physical characteristics. Even at low concentrations, the reinforcing phase exhibits strong interactions with the matrix due to its nanometric composition and high specific surface area (Seretis et al., 2017).

Even though the impact of GNPs on the mechanical characteristics and microstructure of aluminum-matrix composites is now the subject of extensive investigation, the creation of graphene/aluminum composites has caught the interest of several research groups. This is because graphene has exceptional mechanical characteristics and because they have a significant impact on the mechanical behavior of composites made of aluminum. Graphene may be created in single or several layers in this regard. Large portions of graphene have also been successfully created under controlled circumstances (Abdelatty et al., 2021). However, the creation of composites for use in future automotive and aerospace applications necessitates the usage of more material than what is offered by the synthesis methods employed to create a substantial number of graphene layers. In this sense, graphene nanoplatelets (GNPs) are good prospective nanofillers in the manufacture of aluminum-matrix composites because they are made up of many graphene sheets with a stack-like shape and a significant portion of the mechanical characteristics of individual graphene layers. To produce composites with superior mechanical characteristics using GNPs, it is necessary to achieve a homogenous dispersion of the filler inside the matrix. Powder metallurgy processes have led to the development of a number of technologies for the efficient dispersion of nanoparticles. Additionally, mechanical milling-based dispersion techniques improve the efficiency of filler dispersion in the matrix (Pérez-Bustamante et al., 2014).

Due to their desirable qualities, including as their high strength-to-weight ratio, great castability, high ductility, and low density, aluminum alloys are widely used in industrial and domestic settings. Aluminum matrix composites are a viable solution for addressing upcoming structural design difficulties because of the qualities listed above and the variety of applications. Since traditional technologies appear to be incapable of further improving aluminum alloys, the reinforcing material must play a crucial role in enhancing the mechanical performance of composites (Salimi et al., 2011). Both the reinforcement with carbon nanotubes and the reinforcement with graphene fillers have shown favorable impacts on the mechanical characteristics of the composites when used to fabricate aluminum matrix composites. Currently, aluminum matrix composites are being evaluated in order to be put to use in a wide range of novel applications targeted at the automotive and aerospace industries, where the need for lightweight components with specific criteria is constantly growing (Sahu & Sahu, 2018).

The majority of studies during the previous few decades have focused on developing mechanical alloying or ball milling on powder or semi-powder methods to create graphene reinforced aluminum-matrix composites. To produce composites with superior mechanical characteristics using GNPs, it is necessary to achieve a homogenous dispersion of the filler inside the matrix. Powder metallurgy processes have led to the development of a number of technologies for the efficient dispersion of nanoparticles. Additionally, mechanical milling-based dispersion techniques improve the efficiency of filler dispersion in the matrix.

Due to the enormous specific surface area that nanoparticles represent and the robust contact interfacial area that results between the base material and its reinforcement, theproduction of Al-composites with nano-sized reinforcements is currently the subject of various types of experimental inquiry. This property enhances the composites' mechanical behavior, which leads to better nanotribological performance. For improving the performances of AMMCs, a variety of reinforcements, including metallic, amorphous, and ceramic particles, have been used. The final intended and targeted features of the AMMCs determine thereinforcements (Abdelatty et al., 2021).

Recent investigations have shown that the type of reinforcement, its weight percentage, and its distribution within the metal matrix have a significant impact on the characteristics. The distribution of the reinforcing material used inside the matrix must be uniform if we are to maximize the attributes of the AMMCs. To achieve the reinforcements' equal distribution inside the metal matrix, several mixing procedures, including ball milling, molten or liquid metal processes, and solution aided mixing, have been used. Ball milling is one of these methods that has garnered a lot of interest due to its significant influence on the product's microstructure. It produces uniformly distributed reinforcements inside the metal matrix by enhancing the affinity between the reinforcement and the matrix when applied in line with the feed material's optimal working conditions.

The final characteristics of the AMMCs are also influenced by the manufacturing process. AMMCs may be manufactured using a variety of methods, including as casting, thermomechanical processing, and powder metallurgy (PM). The manufacturing approach for AMMCs that is most often used uses the PM method to ensure a high level of uniformity of dispersed reinforcements. The PM technique typically has four majors. The aluminum matrix and reinforcing powders are produced in the first stage, sometimes referred to as the powder preparation stage. The mixing of the aluminum and reinforcing powders takes place during the second step, the ball milling stage. In its third stage, cold pressing is used to create cylindrical pellets from powder ingredients, and its fourth stage, microwave sintering, is utilized to create the final homogeneous product.

Metal matrix composites based on aluminum are created by mixing reinforcement with the metal while it is still in a liquid or solid form. Numerous reinforcing materials, including SiC and CNT, were taken into consideration, and the improvement in mechanical qualities that resulted has been documented in the literature. The issue still lies in attaining uniform particle dispersion. Due to its outstanding mechanical and thermal qualities, graphene is now being evaluated as a viable reinforcing material. One TPa elastic modulus, 125 GPa fracture strength, great thermal stability, and ease of dispersion in many solvents and matrices are only a few of the special qualities of graphene.

The composites in this investigation will be made by stir casting. Another technique used to improve GNP dispersion in the matrix is powder metallurgy. The manufacture of aluminum composites has drawn a lot of interest in the stir casting process. The same strategy was used to create a sizable number of research on many additional MMC systems. One of the main difficulties is achieving homogenous GNP dispersion in the molten metal. Investigating the impact of graphene nanoplatelets on the mechanical and microstructural characteristics of an aluminum matrix composite is the goal of this work. Additionally, it will be investigated how GNP affects the mechanical characteristics of Al, such as their hardness, density, and compression. Field electron scanning electron microscope and X-ray diffraction will be used to characterize the composite's microstructure.

1.1 Problem Statement

Previous research has focused on using mechanical alloying or ball milling methods to create graphene reinforced aluminum-matrix composites. Graphene's exceptional mechanical characteristics make it an attractive choice for enhancing the mechanical behavior of aluminum composites. Graphene nanoplatelets (GNPs) are a prospective nanofiller for aluminum-matrix composites due to their stacked structure and ability to retain essential mechanical characteristics. This is because graphene has exceptional mechanical characteristicsand because they have a significant impact on the mechanical behavior of composites made of aluminum. In this way, single or several layers of graphene can be created. Large portions of graphene have also been made under controlled circumstances.

However, the limitations of traditional aluminum alloys have led to the exploration of reinforcing materials like carbon nanotubes and graphene fillers, which have shown positive impacts on the mechanical properties of aluminum matrix composites. The creation of composite materials for future automotive and aerospace applications requires larger quantities of material than current graphene synthesis methods can provide, making GNPs a promising option for achieving the desired characteristics.

1.2 Objectives of the Study

1.2.1 Primary Objective

1. To determine the best parameters of graphene nanoplatelets on themicrostructural and mechanical properties of aluminum matrix composite.
2. To investigate the microstructural evolution of the aluminum matrix composite.
3. To determine the mechanical properties of the aluminum matrix composite.

1.3 Scope of the Study

In this age of science and technology material plays a very vial role in any technologies development for example development of very light and strong material will tremendously help the aviation industry. In our study we are going to find the effect of graphene nanoplates on the microstructural and mechanical properties of aluminum matrix composites. As it has been found that the at 1D structure the graphene is the strongest material known to man using it's nanoplates into another material will help to increase the strength of that material. So, here in our study we are focused to find the mechanical property of aluminum matrix composites with graphene at different weight percentage. To find out which one is the most effective one.