

INFLUENCE OF NANO-REINFORCED PARTICLES ON THE MECHANICAL PROPERTIES OF ALUMINIUM METAL MATRIX COMPOSITE FABRICATED BY COOLING SLOPE CASTING





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DECLARATION

I hereby, declared this report entitled "Mechanical and Physical Analysis on "Influence of Nano-reinforcement Particles on the Mechanical Properties of Aluminium Metal Matrix Composite Fabricated by Cooling Slope Casting" is the result of my own research except as cited in references.



APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:



ABSTRAK

Nano komposit dengan asas aluminium yang diperkuat dengan zarah nano, mempunyai aplikasi yang luas dalam pelbagai industri, contohnya aeroangkasa, marin, automotif, kerana bahan tersebut ringan, kekuatan tegangan tinggi dan mempunyai yang rintangan kehausan yang tinggi. Sifat mikrostruktur, mekanikal dan tribologi bahan nano komposit adalah penting untuk reka bentuk bahan dalam mencari nilai optimum. Pengukuhan zarah julat mikro atau nano dengan matriks aluminium menghasilkan sifat fizikal dan mekanikal yang lebih baik dalam bahan komposit. Pencirian struktur mikro dan ujian mekanikal matriks komposit A356 dan pelbagai peratusan graphene (0.1, 0.3, 0.5 % berat) yang dihasilkan melalui proses kacau mekanikal dibincangkan dalam kertas kerja ini. Aloi A356 akan digunakan sebagai bahan matriks dan hasil nano graphene melalui kaedah pengurangan grafit oksida akan ditambah. Selepas itu, sampel akan dibuat menggunakan teknik tuangan cerun penyejukan. Parameter optimum untuk mendapatkan dan struktur mikro spesimen adalah berdasarkann skop yang telah ditetapkan. Ujian kekerasan Vickers dan kekuatan tegangan akan digunakan untuk menentukan sifat mekanikal spesimen. Ujian kekuatan tegangan akan dilakukan mengikut piawaian ASTM E8M. اونيومرسيتي تيكنيد

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ABSTRACT

Nanocomposites with aluminium base reinforced with nanoparticles, have wide applications in many industries, for example aerospace, marine, automotive, due to its lightweight, high tensile strength and wear resistance. Microstructure, mechanical, and tribological properties of nanocomposite materials are critical for the reliable and optimal design of novel materials. The reinforcement of micro or nano-sized range particle with aluminium matrix yields improved physical and mechanical properties in composite materials. The microstructure characterisation and mechanical testing of an A356 metal matrix composite with various percentages of graphene (0.1, 0.3, 0.5 % wt) generated by mechanical stirring process are presented in this paper. A356 alloy will be used as the matrix material and nano graphene produce by reduction of graphite oxide method will be added as reinforcement. Following that, the sample will be constructed utilising the cooling slope casting technique. The optimal parameters to get and the globular microstructure of the specimen are stated in the scope. Vickers hardness and tensile strength tests will be used to determine the specimen's mechanical properties. Tensile strength testing will be performed in accordance with ASTM ${\rm e}^{\pm}$ E8M standards.

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DEDICATION

Only my beloved father, Adnan bin Rejab my appreciated mother, Rohayati bt Md Safar my dearest husband, Muhammad Hazwan bin Mohd Rofi my adored sisters, Nur Hanani binti Adnan and Nur Athirah binti Adnan for giving me moral support, money, cooperation, encouragement and also understandings Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS

CSC	-	Cooling slope casting
ASTM	-	American society for testing and materials
MMC	-	Metal matrix composite
SSP	-	Semi-solid processing
SSMP	-	Semi-solid metal processing
SSM	-	Semi-solid metal
SF	-	Shape factor
GF	-	Globule factor
UTM	MALAY	Universal testing machine
OM	- 5	Optical microscope
UTS	- N	Ultimate tensile strength
Al_2O_3	-5	Aluminium Oxide
SiC	- 10	Silicon Carbide
Al	- AINO	Aluminium
Mg	ساملاك-	Magnesium
Cu		Copper
Ti	UNIVERS	Titanium NIKAL MALAYSIA MELAKA
Ni	-	Nickel
Si	-	Silicon
Fe	-	Iron
Mn	-	Manganese
Zn	-	Zinc
SEM	-	Scanning Electron Microscope
XRD	-	X-ray Diffraction
YS	-	Yield strength
Mg ₂ Si	-	Magnesium silicide
S/N	-	Signal-to-noise

LIST OF SYMBOLS



CHAPTER 1

INTRODUCTION

1.1 Background of Study

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Metal matrix composite (MMC) is a composite material which is a combination or a mixture from at least two or more constituent differing in form of metal or other material composition that are essentially insoluble with each other. The new material result with the better properties and the sum of their constituents are produced because both constituents maintain their identity as they are insoluble and melt with each other. Hybrid composition develop by the incorporation of several different types of ceramic particulates into a single matrix. The uses of hybrid composition that contain two or more types of particulates able to help others complement that lacking their own properties and it can increase the value added of the composition. Moreover, the mechanical behaviour of composites is determined by the matrix material composition, size, reinforcement weight percentage, and composite manufacturing technology. The factor that influence of the distribution of the reinforcement particles are rheological behaviour of the matrix melt, interaction of particle and the matrix before during and after missing and lastly the particle incorporation method.

The combination of matrix phase of aluminium and reinforcements phase represent aluminium metal matrix composite. Aluminium matrix composites are a type of engineering material that is widely utilised in the automotive, aerospace, marine, and defence industries, among others. This is because there have high thermal resistance, low density, high corrosion resistance and better mechanical and physical properties. The overall weight of the vehicles able to be reduced by aluminium matrix composite while maintaining satisfactory structural strength.

Thixoforming and rhixocasting are two semi-solid processing (SSP) processes. SSP's capacity is to produce components that meet the stringent requirements of the automotive industry by combining die casting's near-net-shape capabilities and fogging's mechanical properties. From the studies has been made by Taghavi and Ghassemi, the part that produce from thixoforming technique have high sustainability quality compare to the die-casting and forging costs is lower. Nevertheless, it required special block of steel with thixotropic (nondendritic) microstructure is required for thixoforming technique. The cooling slope casting method is one of the several SSP techniques. According to Sahini et al., (2014), cooling slope casting is a simple method that requires very little equipment to execute. The cooling slope casting technique can be used to manufacture feedstock materials for semi-solid processing. Reheating the feedstock to semi-solid temperatures produces nondendritic, spheroidal solid particles in a liquid matrix, which are perfect for thixoforming. This process involves depositing molten metal on top of an angled cooling plate, which causes gravity to accelerate and shear the metal. Following that, the semi-solid slurry is placed into a mould for solidification. It is then reheated at a temperature within the alloy's freezing range to form a globular structure. By adding ultrasonic or mechanical vibration to a solidifying melt, fine, non-dendritic, and spherical structures can be formed.

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1.2 Problem Statement

The formation of non-dendritic microstructure usually difficult and need a lot of cost. Based on Kumar et al. (2014), thixoforming is one of the example technique in producing nondendritic microstructure but due to the high production costs, restricted variety of sizes, and non-uniform microstructure of ingots that can be produced using this technology, thixoforming has not experienced the wide distributed utilisation that it deserves. One of the key contributors to the high cost of creating specialty ingots is the necessity of thixoforming with non-dendritic or globular microstructure.

Furthermore, based on Mabrouk, W.M *et al.* (2021) there is a difference between the formation of coarser α (Al) dendritic phase of non-uniform distribution without semi-solid and semi-solid. The application of semi-solid change the morphology of α (Al) phase from course

structure to fine globular structure with homogeneous distribution. Moreover, the microstructure of A356 alloy without semi-solid show course of dendritic morphology of primary α (Al) phase has a high average size compare to the microstructure of A356 alloy with semi-solid. As the pouring temperature increase, the grain boundaries visible and the α (Al) phase become globular.

Next, the casting defect such as cold flakes and porosity will decrease the tensile strength of the aluminium alloy. The existing of the porosity inside the aluminium alloy casting, it will influence the mechanical properties and yield strength. Furthermore, based on the research has been made by Ahamed and Kato, (2008) the location of the cold flake where the crake started was linked to tensile strength. However, the total area of cold flakes occurring in the fracture surface is related to the strength, therefore the area of the oxide layer was approximated. The stress-strain curves for specimens with and without cold flakes show that the specimen with cold flakes has lower fracture strength and elongation. As a result, the goal of this study is to see how nano-reinforced particles affect the mechanical properties of an aluminium hybrid metal matrix composite formed via cooling slope casting.

1.3 Objective

The objective of this study are:

a) To determine the microstructural evaluation of the aluminium metal matrix composite.

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b) To evaluate the mechanical properties of aluminium metal matrix composite.

1.4 Scope

The scope of the study are:

- a) A356 with nano-graphene (0.1,0.3 and 0.5% wt) as the work piece material.
- b) The parameters for the cooling slope casting are pouring temperature (T), cooling slope length (L) and tilt angle (θ) of the inclined plate.

i) Pouring temperature of 660°C.

ii) Cooling slope length of 300 mm.

iii) Tilt angle (θ) of the incline plate 60°.

- c) The mechanical properties that is evaluated are hardness and tensile test.
- d) Tensile test sample according to the ASTM: E8M standard.

1.5 Significant of study

The significant of study are:

- a) The wear qualities of a hybrid aluminium composite reinforced with graphite and silicon carbide particles were studied, and it was observed that the metal matrix composite had better mechanical and wear properties. The purpose of this study is to look at the mechanical properties of aluminium metal matrix composites.
- b) The presence of metal matrix composite reinforcement has greatly improved the mechanical properties of the Al 356 alloy, such as tensile strength and hardness.
- c) The cooling slope casting parameters have an impact on the microstructure of the aluminium metal matrix composite. This study is being conducted to determine the best settings for the cooling slope casting process for aluminium metal matrix composites.

1.6 Thesis Organization

The thesis is organised as follows. Chapter 1 introduces the research context, problem statement, aims, and scope of the study. The significance of the study is defined in order to more precisely characterise a particular aspect of aluminium metal matrix composite created by cooling slope casting in this thesis. Next in chapter 2, literature review comprises previous research or study about the mechanical properties and microstructures analysis of the aluminium metal matrix composite. Moreover, in this chapter it discuss about the optimum

parameters for the cooling slope casting process and the testing method. Lastly, chapter 3 methodology describe all the raw materials, the method used to prepare the aluminium metal matrix composite, the cooling slope casting process and on how to conduct microstructural analysis, hardness and tensile test.

1.7 Summary

Overall in chapter 1, it consist of background of the study, problem statement, objectives, and scope of the study, significant of study. This chapter dedicated as an introduction to the aluminium metal matrix composite and the process of cooling slope casting. Moreover, chapter 1 also will discuss about the problems that are related to the study and based on the problems, the objective was created to solve the problems. At the end of this chapter, the objective of the study based on the scope will be understand.



CHAPTER 2

LITERATURE REVIEW

This chapter explains the content, steps and point that are related to the study. All data collected from articles, journals, and published literature pertaining to the cooling slope casting method, microstructure, and mechanical properties of aluminium metal matrix composite. Chapter 2 examines the effect of nano-reinforced particles on the mechanical characteristics of an aluminium metal matrix composite produced via cooling slope casting. Furthermore, this chapter discuss about the tensile strength, hardness and microstructural of aluminium metal matric composite.

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2.1 Aluminium alloy and metal matrix composite (MMC)

2.1.1 Overview of A356 alloys

A356 alloys are composed primarily of aluminium (Al), with copper, magnesium, manganese, silicon, and zinc serving as distinguishing alloying components. A356 is typically utilised in engineering structures and components where light weight and resistance to corrosion are required. Since the debut of metal-skinned aircraft, alloys based mostly on aluminium have played a significant role in aerospace manufacturing. Aluminium-magnesium alloys are lighter and less combustible than other aluminium alloys. If anodizing and other

corrosion-resistant coating processes are not used, A356 alloy surfaces will form a white, protective layer of corrosion-resistant aluminium oxide.

According to Dwivedi et al. (2014), galvanic corrosion can occur in a damp environment when an A356 alloy comes into electrical contact with other metals that have higher negative corrosion potentials than aluminium and there is an electrolyte present to facilitate ion exchange. Heat treatment of aluminium alloys can result in uncomfortably high temperatures. Internal element separation occurs as a result, and the metal corrodes from the inside out. A356 alloy corrosion is something that aircraft mechanics deal with on a regular basis. Additionally, experiments conducted on A356 indicate that the elastic modulus of A356 alloys is naturally about 70 GPa, which is approximately one-third of the elastic modulus of the bulk of steels and steel alloys. As a result, A356 alloy components flex more elastically than steel ones of the same size and form under the same load. There are A356 alloys with somewhat higher tensile strengths than commonly used steels.

Table 1.1: Example of A356 chemical composition

Element	Si	Mg	Fe	Ti	Cu	Mn	Zn	Ni	Al
Weight%	6.6	0.45	0.10	0.10	0.05	0.055	0.005	0.005	Bal.

2.1.2 Metal matrix composite UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Metal matrix composites (MMCs) are a subset of engineering materials defined by the use of a light metal base reinforced with various types of reinforcement to enhance the material's qualities. Aluminum (Al), magnesium (Mg), copper (Cu), and titanium (Ti) are all examples of materials that are frequently utilised as the basis for composites. Additionally, metal matrix nanocomposites are a novel family of materials that incorporate nanoscale reinforcement (1-100 nm).

An experiment has been made by Velickovic *et al.*, (2019) prove that, The curves produced by nanoindentation of samples of A356 alloys and nanocomposites with reinforcement content of 0.2, 0.3, and 0.5 wt.% SiC show that the obtained values of the nanocomposite's hardness are greater than the base alloy. The difference in material hardness may be noticed in the indentation depths of the indenter into the test samples (figure 2.1), with

the larger the indentation depth indicating a lower hardness value. Then, in terms of elastic modulus, it can be stated that increasing the percentage content of the reinforcement has no significant effect on the value of the elastic modulus. It can also be deduced that the decreased indentation depth implies that the base has been strengthened with silicon carbide. The presence of agglomeration and porosity in nanocomposite materials is well understood to have a negative impact on their mechanical characteristics.



Figure 2.1: Mechanical properties (hardness) as a function of the impression depth (Velickovic *et al.*, 2019)

اونيون سيتي تيڪنيڪل مليسيا ملاك and Rajendra Prasad (2016) tested in tensile strength testing on diff

Gowda and Rajendra Prasad (2016) tested in tensile strength testing on different mixes of RHA and Al2O3 particles reinforcing materials, as well as ageing circumstances. The percent elongation and UTS (ultimate tensile strength) were measured. Ultimate tensile strength (UTS) improves as the weight percent of RHA and Al_2O_3 reinforcement particles increases, while percent elongation reduces as the weight percent of RHA and Al_2O_3 reinforcement particles increases. This is because dislocation resistance increases with weight percent, and so strength increases with weight percent. The enhancement of tensile strength is favoured by effective bonding between reinforcements and matrix. An experiment has been made by Pugalethi, Jayaraman and Natarajan, (2015) to determine the tensile strength using different composition shows the same result as the experiment made by Gowda and Rajendra Prasad.

Sample	Composition	Tensile Strength	Elongation %
No.		(MPa)	
1	Al7075 alloy+2% of SiC+3% of Al_2O_3	305	5.011
2	Al7075 alloy+2% of SiC+5% of Al_2O_3	378	3.987
3	Al7075 alloy+2% of SiC+7% of Al_2O_3	332	3.112
4	Al7075 alloy+2% of SiC+9% of Al_2O_3	402.5	2.789

Table 2.2 Tensile Strength Values of test samples (Pugalethi, Jayaraman and Natarajan, 2015)

The microstructures recorded were examined in order to anticipate the presence of two particles in the alloy matrix. It may deduce from the microstructure analysis that there is a uniform distribution of reinforcements in the alloy matrix. The connection between particles is adequate, and finer alloy matrix grains are discovered.



Figure 2.2: Microstructure of (a) Pure Al356 (b) $2\% Al_2O_3$ (c) $2.5\% Al_2O_3$ (d) $3\% Al_2O_3$ (Tenali, Tejaswini and P, 2019)

2.2 Cooling slope casting

2.2.1 Overview of cooling slope casting

Cooling slope casting is one of numerous Semi Solid Metal Processing (SSMP) processes. Cooling slope casting is a low-cost method of casting that generates feedstock

material for semisolid metal processing. When heated to semisolid temperatures, the feedstock yields nondendritic, spheroidal solid particles suspended in a liquid matrix ideal for thixoforming. Then, Yadav and Chakrabarty, (2020) said that casting using cool slope is one of the most used SSMP technique. Superheated molten metal allowed to flow over an angled cooling plate in this process. In the unexpectedly undercooled melt that comes into contact with the cooling plate, with very fine nucleation sites occur. Shear tension and melt flows detach these nuclei from the surface, resulting in a uniform distribution of nuclei throughout the melt. Through the research has been made from Tugiman *et al.*, (2019) cooling slope method was applied in many types of alloy system such as A356, AlSi7Mg and AA 7075 wrought aluminium alloy. Moreover, the previous researcher state that the technique was success to change the microstructure and mechanical properties of Al alloy.

According to Kumar et al. (2014), cooling slope casting is an upcoming semi-solid technique that requires simple equipment and minimal operating expenses. Cooling slope casting is a straightforward process that includes pouring molten metal over a cooling slope plate at a proper superheat level and subsequently solidifying in the mould. The material of the mould, the temperature of the mould, the length of the cooling slope, the angle of the cooling slope, the superheat, and the pouring temperature are all process variables that affect the final microstructure of the solidified slurry. As a result, the purpose of this study is to find the optimal parameters for the aluminium metal matrix composite cooling slope casting method.





(a)



(b)

Figure 2.3: The cooling slope casting apparatus (a) a photograph (b) schematic illustration (Adss *et al.*, 2016)

2.2.2 Parameters of cooling slope casting

There are several parameters in cooling slope casting process, the first parameters is pouring temperature. Pouring temperature give the biggest influence on the microstructure of semi-solid Aluminium alloys. According to Liu et al. (2011), the fine-grained -Al grains and their sphericity are critical in the thixoforming process. According to Legoretta et al. (2008), superheating has the greatest effect on shape factor and particle size. They demonstrate that the form factor in the core of an A356 alloy ingot varied from 1.4 at 620°C to 2.6 at 680°C depending on the pouring temperature. In comparison to greater pouring temperatures, the low superheated generated a much finer microstructure. A similar trend has been reported by Adss *et al.*, (2016) which is at with increasing pouring temperature, the constant tilt and cooling slope raises a minor portion of the average form factor for primary -Al grains. For example, if the pouring temperature is increased from 620°C to 630°C at a constant angle of 30° and a cooling slope length of 200mm, the average form factor increases from 0.7791 to 7891.

Furthermore, Xu et al., 2011 discovered the same result on 3356 alloy, proving that by lowering the pouring temperature, the microstructure can be converted from dendritic to fine spheroidal. Das et al. (2012) used an Eulerian two-phase flow technique to develop a numerical model and simulate the liquid metal flow of A356 alloy through a cooling channel, and the effect of pouring temperature on the cooling channel semisolid slurry formation process was

investigated. From the development, they reported that there are three different temperatures give the best result which is 687°C, 672°C and 650°C.

The length of the cooling slope is the next parameter to consider. The length of the cooling slope has a direct effect on the cooling-shearing time of the melt and, as a result, influences the microstructure of the semi-solid melt. Haga and Suzuki (2001) conducted an experiment and found that a 300 mm slope length yielded spherical primary crystals compared to a 100 mm slope length. According to Motegi et al., (2002), if the length is too short, inadequate nucleation may occur. However, if the slope is sufficiently long, a slurry of a solid shell could form on the slope. As a result, by increasing the cool-shear duration, an optimal pouring temperature influences the transformation of coarse dendrites into rosette shape grains. By examining the effect of length on the microstructure of A356, Taghavi and Ghassemi (2009) demonstrated that an optimum length with the smallest grain size and maximum sphericity was attainable at a constant angle. When the slope is between 40° and 50°, and the inclined plate is between 200 mm and 400 mm, the grain refinement improves, with the size of the -A1 phase shifting to 28-32 m and the form factor improving to 0.67-0.70.

The angle of the inclined plate is the final parameter. The cooling slope's inclination controls the flow velocity and contact duration between the cooling plate and the molten alloy. Adss et al. (2016) discovered that increasing the inclined plate angle from 30° to 45° decreases the average size of the primary α -Al grains at constant pouring temperature and length. The major grain size of α -Al has been decreased from 59.82m to 54.22m. Then, by raising the tilt angle beyond 45°, the average size of the primary α -Al grains tends to rise. Furthermore, as the angle of the slanted plate increases, so does the shear stress, which aids in the breakdown of the dendritic microstructure and the formation of smaller grains.

Xu et al. (2011) shown that raising the tilt angle has an effect on the microstructure of A356. By increasing the angle from 30° to 45° , the size of the α -Al phase is reduced from 71m to 65m and the form factor of the -Al phase is reduced from 1.8 to 1.4. Additionally, increasing the angle from 45° to 60° increased the size and shape of the α -Al phase to 85m and the shape factor to 2.2. Following that, Taghavi and Ghassemi (2009) evaluated the effect of various angles on an inclined plate made of A356 alloy, including 30° , 40° , 50° , and 60° . The study revealed that an inclined plate at a 30° angle cannot totally eliminate the α -Al phase's dendritic shape in the microstructure. While the dendritic microstructure is removed, the globular microstructure is replaced for all lengths at 40° and 50° lead angles. Increasing the angle from

 50° to 60° , however, results in an increase in the size of the α -Al phase. According to Sahini et al. (2014), when the plate angle is greater than the optimal angle, the time spent by the molten metal in contact with the inclined plate decreases, the alloy flows faster, resulting in less dendritic arm breakage, and the heat transfer between the melt and the inclined plate surface decreases, resulting in less nucleation. As a result, the flow velocity and duration of contact between the molten metal alloy and the cooling plate angle increase, resulting in an increase in the severity of shear stress and dendritic fragmentation.

2.2.3 Advantages and disadvantages of cooling slope casting

The advantages of cooling slope casting are discuss by Sahini *et al.*, (2014) which is the technology that used in cooling slope casting is basic and attractive because there is no special equipment needed to perform the process. It is a straightforward processing technique, with relatively minimal equipment and operating expenses connected with the cooling slope. Next, when the cast alloy is heated to a semi-solid temperature, the method produces a globular or spheroidal microstructure, which is ideal for isotropic mechanical characteristic and toughness. Zhao *et al.*, (2013) said that cooling slope plate process is not only slurry preparation technique, but also an efficient grain refining method with notable cost and efficiency benefits, therefore it is projected to be a competitive approach with a wide range of applications. Beside the advantages, there are some limitations of cooling slope casting. In cooling slope casting process, the production of casting flaws, including holes and oxide, causing thixoformed cooling slope product to have inferior mechanical qualities. Then, on the surface of the slope plate, there is a propensity for solidification shell development which may affect the morphology of the primary α -Al phase.

2.3 Microstructure of metal matrix composite

2.3.1 Comparison between conventional casting and cooling slope casting microstructure.

According to Abdelsalam et al., (2015), the microstructure of standard cast A356 monolithic alloy consists of typical dendritic structure. Large dendrites of α -Al grains with

lengths of more than 100 m have been discovered. The structure of the monolithic A356 Al alloy is largely made up of primary α -Al dendrites (white patches) and a eutectic mixture of - Al and Si, as shown in figure 2.4. (darker regions). Primary Si particles in the shape of needles were found at the dendritic borders of the α -Al dendrites. Next, the microstructure that produced by cooling slope casting was finer towards the bottom of the ingots as opposed to the top. Additionally, the ingots' radius had the smallest grain size as compared to their mid-radius and centre. While the grain size in the centre of ingots was the largest, the grain size in the radius of the ingots' mid-radius was the smallest. The finer granules on the edge were supposed to be the result of higher heat loss through the mold's wall.



Figure 2.5: Boundary condition that set for simulation (Kolahdooz and Aminian, 2019)



Figure 2.6: Microstructure of the conventional cast A356 monolithic alloy (Abdelsalam et al., 2015)



Figure 2.7: Microstructure of A356 monolithic alloy ingot produced using cooling slope casting (Abdelsalam *et al.*, 2015)

2.3.2 Effect of the pouring temperature variation on microstructure.

An experiment conducted by Nourouzi et al., (2012) demonstrated that near the surface of the ingot, finer microstructure appears at lower superheat compared to greater pouring temperature (72 m vs 91.7 m). At the wall zone of the ingots and the dendritic structure, the form factor is always low, ranging from 0.33 to 0.42. Frictional solidification on the cooling slope causes dendritic structure degradation and refining of the morphology of the primary α -Al phase in cooling slope casting ingots. The microstructure of a cooling slope casting with pouring temperatures of 650°C and 625°C and a mould temperature of 25°C is shown in Figure 2.8. With the exception of a narrower wall zone, the microstructure of the parent alloy changes substantially during cooling slope casting. In the centre of the ingots, the primary phase morphology has completely changed to a non-dendritic morphology. At pouring temperatures of 650°C, the fraction of the solid phase produced as a result of crystal nucleation and detachment from the cooling plate's surface was inadequate to generate fine and spheroidal primary crystals. The centre zone exhibits rosettes and approximately semi-globular character, the middle zone exhibits rosettes, and the wall zone exhibits dendritic character. Reduce the pouring temperature to 625°C to improve the rate of nucleation and detachment of α -Al crystals. As a result, the dendritic structure deteriorates and is replaced by finer, practically spherical primary α -Al particles.



Figure 2.8: Semi-solid microstructure developed at a mould temperature of 25°C and pouring temperatures of 650°C and 625°C: (a) 650°C at the center zone, (b) 650°C at the middle zone, (c) 650°C at the wall zone, (d) 625°C at the center zone, (e) 625°C at the middle zone, (f) 625°C at the wall zone (Nourouzi *et al.*, 2012)

2.3.3 Effect of the angle of the inclined plate variation on microstructure.

Based on the experiment has been made by Mehmood *et al.*, (2016) there are a few samples on the microstructure produced from the different angle of the inclined plate. The first sample shows that the 15° cast specimen show elongated dendritic growth. The grain boundaries was visible and it form tree like structure. The grain boundaries exhibit linked precipitate morphologies, and some isolated crystals can be identified. Following that, the 30° cast sample exhibited dendritic structure, uneven form, and eutectic phase deposition. Thicker precipitate morphology was seen at grain boundaries, but it still had a somewhat continuous structure. At 40°, dendritic development occurs, resulting in decreased porosity, an irregular grain structure, and thinner but still continuous precipitate morphologies. At 60°, globular morphologies were observed, as well as some pores.

Even though grain refining appears to expand the location for precipitate nucleation and facilitate precipitate clustering, the actual grain size does not appear to be much reduced. The final sample has a temperature of 75°, and the dendritic development and cracks that have developed and precipitated are thick and discontinuous. In conclusion, grain size was about the same at inclination angles of 15°, 30°, and 45°. The grain size decreased from 221m to 209m at the maximum sloping plate angle of 75° and pouring temperature of 800°C. At a slope angle of 75° and a pouring temperature of 800°C, the smallest grain size was determined to be 201m.



(d)

(c)



Figure 2.9: Microstructure of cast specimens with varying sloping angles, scale 20μm 500 x magnificent. (a) Slope angle 15° (b) Slope angle 30° (c) Slope angle 45° (d) Slope angle 60° (e) Slope angle 75° (Mehmood *et al.*, 2016)

2.3.4 Effect of the length of cooling slope on the variation of microstructure.

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Ranjan and Ghose, (2021) said that another aspect that determines the size and shape of microstructure is the length of the cooling slope it play a major role in cooling the liquid metal. The increased length of the cooling slope allows for additional cooling time and imposes shear force on the melt. As a result of detaching more fractured solid phases, fine and spherical primary phases emerge in the microstructure. It was discovered that increasing the slope angle resulted in a reduction in heat transmission owing to the creation of a thick solid layer on the surface. The a-primary phase nucleation rate is reduced as a result of the aforementioned impact. Taguchi approach was used to investigate the influence of process factors on the form factor of primary grains. The slope length and slope angles were determined to have a 50% and a 23% influence to the form factor, respectively. Another cooling slope casting experiment shown that the relationship between slope length and pouring rate had a greater effect on sphericity than any other process parameter. Additionally, they demonstrated that increasing the angle and length of the slope increased grain size while lowering the form factor, particle density, and primary a-phase fraction. Notably, the microstructure of semi-solid metal (SSM) castings has a major effect on their mechanical properties. Numerous scholars investigated the appropriate slope angle and length of the slope for the production of globular microstructures.



Figure 2.10: Microstructure of ingots cast over a cooling plate with a cooling length of 200 millimetres and pouring temperatures (a) 640°C, (b) 630°C, (c) 620°C (Ranjan, Surekha and

Ghose, 2021)



Figure 2.11: Microstructure of feedstock (a) cast over the cooling slope casting surface with pouring temperature of 640°C and slope length of 400 mm and isothermal holding at 580°C for (b) 5 minutes



Figure 2.12: Microstructure of feedstock (c) 15 minutes (d) 30 minutes (Ranjan, Surekha and Ghose, 2021)

2.4 Mechanical properties of aluminium metal matrix composite.

2.4.1 Tensile strength

A 356 alloy was tensile tested by Das et al., (2012). It demonstrates that the cooling slope rheocasting process's transition of the primary phase shape from dendritic to near

spherical is responsible for the improvement in strength and elongation characteristics. Large and elongated particles (dendrites) present in gravity cast A356 alloy display a greater degree of strain hardening, resulting in a higher rate of damage accumulation owing to particle cracking. Dendritic structure also contributes to the production of microporosty by forming a solid skeleton inside the melt during solidification and limiting its fluidity, resulting in air pockets (microposity) in the solidified ingots and a detrimental effect on mechanical characteristics. The almost spherical primary phase formed during rheocasting minimises microporous material formation while also promoting the switch of fracture mode from intergranular to transgranular, which results in the better mechanical properties of rheocast alloy.



Figure 2.13: (a) Tensile results of various conditions and (b) dimensions of tensile sample (Das, UNIVERSITI Samanta, Ray, *et al.*, 2012) SIA MELAKA

Furthermore, Mabrouk *et al.*, (2021) discovered that, the ultimate tensile strength and elongation of alloy with semisolid casting are greater than the alloy without semisolid casting. Implying that semisolid casting of the investigated A356 alloy able to improve its ultimate tensile strength and elongation. The investigated alloy's ultimate tensile strength and elongation increase significantly from 102 MPa and 1.175% without semisolid casting to 113 MPa and 3.6% with semisolid casting at the optimum pouring temperature of 640°C respectively and then gradually decreases as the pouring temperature increases. The tiny microstructure of engineering alloys is widely recognised to give advantages to their tensile performance. Figure 6 depicts SEM micrographs of the fracture surfaces of the examined A356 alloy, both without and with semisolid casting, at the optimal pouring temperature of 640°C. Figure 2.14 (a) shows SEM micrographs of the fracture surface of the examined A356 alloy
without semisolid casting, which reveals few dimples and a non-uniform distribution, indicating a dimpled quasi-cleavage fracture process. Semisolid casting at the optimum pouring temperature of 640°C modifies and refines most of the primary α -Al phases, and the deformation zone on the fractography of the alloy is enlarged significantly, and the dimples are deep and distributed uniformly, as shown in figure 2.14, increasing its tensile strength and elongation. The fracture mode shifts to ductile fracture. As a result, the fracture was mostly driven by dimple rupture with shattered eutectic silicon particles and revealed an intergranular fracture mode, resulting in the best mechanical properties.



Figure 2.14: SEM micrographs of the fracture surfaces of the investigated A356 alloy (a) without semisolid casting and (b) with semisolid casting with optimum pouring temperature of 640°C. (Mabrouk *et al.*, 2021)

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Moreover, based on the experiment that has been made by Tugiman *et al.*, (2019) to investigate the ultimate tensile strength of aluminium-Si alloy re-casting by cooling slope method with different tilt angle. The maximum value of 135 MPa of tensile strength at 45°C inclined was obtained. The tensile strength of the aluminium alloy decreases because of casting defect such as cold flakes and porosity. The deterioration of tensile strength can cause the porosity inside the cast material. Moreover, fracturing occur at the high concentration of porosity area.



Figure 2.15: Fracture surface of tensile materials in various tilt angle (a) 15° and (b) 30° (Tugiman *et al.*, 2019)



Figure 2.16: Fracture surface of tensile materials in various tilt angle (c) 45°, (d) 60° and (e) 75° (Tugiman *et al.*, 2019)

Figure 2.15 and figure 2.16 shows the casting defects that was found in all specimen. Internal defects such as porosity of various size were detected in numerous sections of the specimens it is represent by arrow number 1 in the picture (a), (b), (c), (d) and (e). The casting defect such as gas porosity and blowhole are usual defect that is found in the materials. The mechanical properties and yield strength of the materials will be affected by the existing of porosity inside the aluminium casting. The surface is seen flat with a small black patch, and the diameter of the specimens seems to be the same size around the fracture area. Based on this characteristic, it may be assumed that the samples have low elongation.

2.4.2 Hardness test

Hardness test by using Vickers hardness test has been performed by Ir Ts Mohd Shukor Salleh, MKamal and Mohamad, (2016) proved that, compare to the conventional and cooling slope casting process, cooling slope casting process has a higher average of hardness value of the alloy which is poured at 660°C in cooling slope casting with the slope length of 300 mm. The hardness value increased from 70.83 HV up to the 78.77 HV. The formation of globular microstructure in the alloy allowed an increasing of the hardness value of the cooling slope sample. α -Al particles grow smaller and more evenly distributed through the sample. Compare to the conventional cast sample, the globular shape in the cooling slope sample occupied more eutectic phase.



Figure 2.17: Vickers hardness of conventional cast alloy and cooling slope cast alloy at different pouring temperature and slope length (Ir Ts Mohd Shukor Salleh, MKamal and Mohamad, 2016)

Based on Tugiman *et al.*, (2019), the hardness of the aluminium alloys reduced significantly as the tilt angle increased due to a higher flow rate of aluminium filling the permanent mold cavity. It is hypothesised that the heat transfer rate on the surface of the plate due to the higher direct contact with air than on the interior of the permanent mold. The development of the grain was caused by the delay of the heat transmission between the aluminium melt and the mold. The reduced hardness produced in this study is owing to the larger α -Al grain generated with the high tilt angle.



Figure 2.18: Hardness of aluminium-silicon alloy in various tilt angle of the cooling slope (Tugiman *et al.*, 2019)

As shown is figure 12 below, at the angle of 15° the impact strength was about 8 Joules and the number increased as the tilt angle to 45° which is at 12 Joules. Moreover, the increasing of the tilt angle tends to lower the impact energy up to 75°. The impact strength of the aluminium casting differs between the bottom and top regions, with the standard deviation of many samples being larger than others. Many parameters including pouring temperature, porosity, defect and microstructure shape were thought to influence the impact strength of casting materials.



Figure 2.19: The impact resistance of aluminium-silicon alloy in various tilt angle of cooling slope (Tugiman *et al.*, 2019)

2.5 Summary

In this chapter, there are various types of material that will produce a metal matrix composite. The most crucial section of this chapter is determining the optimal parameters for the cooling slope casting process, since these parameters will have an effect on the microstructure and mechanical properties of the aluminium metal matrix composite. Based on the previous research, most of the researchers identify that the optimum tilt angle of incline plate is 60° the optimum length of cooling slope is 300 mm and pouring temperatures is 660°C The microstructure of the sample will influence the mechanical properties of the sample.



CHAPTER 3

METHODOLOGY

This chapter provides an explanation of the methodologies used in this investigation. It included information on the process procedures for cooling slope casting graphene-reinforced A356 aluminium composites. This chapter also covers the project's progress and the precise technique employed to meet the goals of the project and achieve the desired outcome.

3.1 Gantt Chart

Gantt charts are an excellent tool for project scheduling and tracking the duration of each job in the project. The Gantt chart is typically used in project management, and it displays all of the tasks graphically. Planning and monitoring the project's progress are typically helpful. Gantt charts are used to ensure that the task or obligations are completed within the allotted time and to maintain the project's course. As a result, a Gantt chart is created and provided in Appendix A for Final Year Project 1 and Appendix B for Final Year Project II.

3.2 Flow Chart



Figure 3.1: Flow chart of the process

3.3 Relationship between Objectives and Methodology

The aim of this study is to achieve the relationship between the objectives and the methodology that need to be carried as describes in Table 3.1. The best methods will be used for each of the objectives stated to solve the problems in this study. The machine and software that required to fulfil the objectives of the study will be provided by Faculty of Manufacturing Engineering.

Objectives	Method				
To determine the microstructural evaluation	Microstructure characterization: Optical				
of the aluminium metal matrix composite.	Microscopy (OM), Scanning Electron				
	Microscope (SEM), X-ray Diffraction				
WALAYSIA 4	(XRD)				
To evaluate the mechanical properties of the	Tensile test: Samples are tensile tested in				
aluminium metal matrix composite.	accordance with the ASTM: E8M standard.				
	Hardens test: Vickers hardness tester				

Table 3.1: Relations	hip between	objectives and	methodology
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3.4 Experimental Procedure

3.4.1 Materials preparation UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Element	Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Ti	Cr	Sn	Al
wt. %	6.5	0.35	0.20	0.10	0.45	0.10	0.10	0.10	0.20	0.10	0.05	Bal.

Table 3.2: Chemical composition of A356 alloy (wt. %)

3.4.2 Feedstock Production by using Cooling Slope Casting

Figure 3.2 illustrated the schematic diagram of the experiment setup for feedstock preparation by using cooling slope casting.



Figure 3.2: Schematic illustration of cooling slope casting

Before melting in the furnace as seen in Figure 3.5, 200g of the manufactured A356 alloy were weighed using the weighing equipment (Figure 3.3) to generate a billet sample (Figure 3.5). At a temperature of 700°C, each alloy was melted and superheated in a silicon carbide crucible using a portable melting furnace with a maximum temperature of 1000°C and an argon environment.

The nano-graphene powder was then encased in aluminium foil before being plunged into the molten A356 alloy with a plunger. There were 0.1wt %, 0.3wt %, and 0.5wt % of nano-graphene present. The mixture was stirred for 10 minutes using a mechanical stirrer of turbine design rotating at 400 rpm. The mixture was then instantly placed onto the cooling slope, which had a length of 300mm and an angle of 60°, and it will enter the cylindrical mould when the temperature decreases to 660°C.



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Figure 3.3: Weighing machine



Figure 3.4: Bandsaw machine (FKP,UTeM)



Figure 3.5: Portable melting furnace



Figure 3.6: Cooling slope casting



3.5 Microstructural Analysis

3.5.1 Sample Preparation

The sample of cooling slope casting was cut into multiple sections (about 6mm thick) for microstructure testing. To eliminate surface flaws, the samples were ground on a spinning abrasive disc with 240, 400, 600, 800, and 1200 grit silicon carbide (SiC) sheets. Then, continue polishing the surface with micron diamond paste of 6 μ m and 1 μ m until the surface becomes mirror-like. After 10 seconds of etching in Kellar's agent to remove contaminants from the surface of the sample, microstructural analysis was then performed.

3.5.2 Optical Microscopy

The sample microstructure image was studied using an Olympus optical microscope (OM). The cooling slope casting samples were metallographically examined, and their microstructure was subsequently characterised.

3.5.3 Scanning Electron Microscopy (SEM)

SEM is used to determine the various phases of samples from cooling slope casting. Utilizing SEM, the distribution and interfacial characteristics of graphene in the A356 matrix were also studied. At high magnification, backscatter electron imaging of SEM provided a grayscale image that was utilised to examine the morphology and composition of the materials.



Figure 3.9: SEM-EDX machine (FKP, UTeM)

3.5.5 X-Ray Diffraction Analysis (XRD)

X-ray Diffraction is utilised to unequivocally examine the phase analysis and composition of the samples. In XRD analysis, the characterization x-ray diffraction pattern is produced, which provides information on crystal structure, phase, grain size, and crystal defects. In this experiment, different phases of cooling slope casting samples were identified and confirmed using XRD. In addition, the XRD scan can be used to obtain aluminium samples with varying graphene concentrations.

3.6 Mechanical Testing

3.6.1 Hardness Test

In this investigation, a Vikers Hardness Tester, as depicted in Figure 3.10, was utilised to measure hardness. The HV hardness was determined by applying a 10 N load for 10 seconds. The cooling slope casting sample was initially ground with 240-grit silicon carbide (SiC) paper. After the grinding operation was done, a test for hardness was conducted. Therefore, the average values were derived from five measurements made on a single sample.



Figure 3.10: Vikers hardness tester (FKM, UTeM)

3.6.2 Tensile Test

3.6.2.1 Sample Preparation

The cooling slope casting sample was cut using Wire Electrical Discharge Machining, also referred to as Wire-cut EDM (Figure 3.14) with a diameter of 10mm and a length of 65mm. Utilizing CNC Turning Machining, mostly dog-bone shaped tensile specimens were utilised in tensile tests. In accordance with the ASTM: E8M standard, tiny specimens of the ratio 4:12:5 were employed, as stated in Table 3.1. All samples were acquired

in the dog-bone configuration with gauge section dimensions of 20 mm in length, as specified by the ASTM E8M standard.



Figure 3.11: EDM wire-cut machine (FKP,UTeM)



Table 3.3:	Tensile tes	t dimensions	– ASTM	E8M
1 4010 5.5.		a minemonomo	1 10 1 111	10101

U	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
G-Gauge	62.5 ± 0.1	4.5 ± 0.1	30.0 ± 0.1	20.0 ± 0.1	12.5 ± 0.1
length, mm					
D-Diameter,	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1	4.0 ± 0.1	2.5 ± 0.1
mm					
R-Radius of	10	8	6	4	2
fillet, min					
A-Length of	75	54	36	24	20
reduced					
section, min					

3.6.2.2 Testing

A 100Kn Universal Testing Machine (UTM) with a constant cross-head speed of 5.0mm/min was utilised for the tensile test, which was performed in ambient temperature conditions. The results of the tensile strength graph were used to calculate elongation values up to and including fracture. In contrast, a 0.2% plastic strain offset was used to determine the yield stress.



Figure 3.14: Setup of tensile test sample (FKP, UTeM)

3.7 Summary

Comparing the cooling slope casting method to the traditional casting process for the metal matrix composite, it is projected that the cooling slope casting process will result in a reduction in casting defect. Additionally, the microstructure created by cooling slope casting is superior to that produced by conventional casting. It is discovered that by reducing casting defects such as porosity, the specimen's tensile strength can be increased. Thus, tensile strength test is performed in this study. Furthermore, the microstructure of the specimen will influence the hardness of the specimen. In this study the microstructures characterization will be perform in order to identify the difference between the A356 with different weight percentage of graphene (0.1, 0.3 and 0.5 wt.%).



CHAPTER 4

RESULT AND DISCUSSION

This chapter discussed the surface morphology, element composition, tensile strength, and hardness of the nano-reinforced particles on A356 produced by cooling slope casting. Each sample was selected for material characterization and mechanical testing. Thus, all the acquired data were analysed and interpreted to reveal the findings, and the interpretation of the results was debated in order to have a deeper grasp of the primary problem and its solution.

4.1 Material Characterization TEKNIKAL MALAYSIA MELAKA

4.1.1 Optical Microscopy Analysis



Figure 4.1: The microstructure of A356 + 0.1 wt% graphene (a) top, (b) center and (c) bottom



Figure 4.2: The microstructure of A356 + 0.5 wt% graphene (a) top, (b) center and (c) bottom



Figure 4.3: The microstructure of A356 + 0.3 wt% graphene (a) top, (b) center and (c) bottom

After the cooling slope casting process was completed, it was observed that the microstructure of A356 with varying graphene weight percents was non-dendritic. According to the diagram, the bright phase represents the primary α -Al phase, while the dark region surrounding it represents the eutectic α -Al phase. According to N.N.M. Ishak (2014), during the cooling slope casting process, the shearing effect on the cooling slope plate fragments and modifies the dendriatic arm into an almost spherical microstructure. There are four stages of microstructural evolution, beginning with dendritic growth and continuing through rosette, repented rosette, and globular formation at the bottom of the slope plate. The grain size will be affected by the slope cooling procedure. As a result of the presence of water, the grain size produced by the cooling slope casting method will be smaller than conventional casting.

As the molten metal flows down the cooling slope, it has cooled more quickly due to the water cooling. It is possible to increase the nucleation rate by increasing the pace of cooling. Changes in nucleation rate will affect the grain size and form factor of primary α -Al grains. In general, the tensile characteristics of an engineering alloy benefit from a fine microtexture. According to Morerover, Kumar et al. (2014), cooling slope processing is a promising technique for producing feed stock materials of alloy and metal matrix composites with high mechanical qualities suited for thixoforming operations. After a partial remelting procedure, the shape of the primary A356 and graphene grains in the composite are globular and/or elliptic.

4.1.2 Scanning Electron Microscopy (SEM) Analysis

Using Scanning Electron Microscopy, the microstructure of A356 with varying percentages of graphene composite formed by cooling slope casting was examined (SEM). The microstructure of metal matrix composite ware formed by cooling slope casting is analysed based on the nano-graphene content. Figures 4.4, 4.5, and 4.6 depict the composite microstructure of A356/Graphene. According to the image below, the microstructure of the A356/Graphene composite has a globular or rosette-like appearance because it was manufactured utilising the cooling slope casting technique. In addition, the grain size increases as the nano-graphene concentration rises. However, none of the samples below demonstrated a significant difference in reinforcement types. The mechanical characteristics of a material can be improved by distributing Si particles more finely and uniformly around α -Al globules.





Figure 4.4: SEM image of A356 + 0.1 wt% graphene with magnification of (a) 200, (b) 500, (c) 1000



Figure 4.5: SEM image of A356 + 0.3 wt% graphene with magnification of (a) 200, (b) 500, (c) 1000



Figure 4.6: SEM image of A356 + 0.5 wt% graphene with magnification of (a) 200, (b) 500, (c) 1000

4.1.2 X-ray Diffraction (XRD) Analysis

X-ray Diffraction analysis was used to confirm the intermetallic compounds of each sample. As illustrated in Figures 4.7, 4.8, and 4.9, the X-ray Diffraction pattern revealed that each phase had formed at its corresponding peak in the A356/Graphene composite manufactured via cooling slope casting.



Figure 4.8: XRD pattern of sample 2 A356 + 0.3 wt% graphene



Figure 4.9: XRD pattern of sample 3 A356 + 0.5 wt% graphene

The X-ray Diffraction pattern for cooling casting samples reveals each phase created at each peak in the A356/Graphene composites. In the XRD pattern, four phases (Mg_2Si , SiC, Al, and C) could be observed. Due to the inability of the XRD technique to detect the phases in detail, the other peaks of the composites could not be identified. The highest peak for Mg_2Si indicated that the cooling slope casting of A356/Graphene composites included the highest concentration of Mg_2Si among all samples examined. The intensity of Mg_2Si in sample three, which is A356 plus 0.5 wt % graphene, was the highest among the samples, indicating that the material may include composites with superior mechanical capabilities.

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4.2 Mechanical Testing

4.2.1 Hardness test

The result obtained from the Vickers Hardness Test (HV) for each samples were tabulated as shown in Table 4.1. The tabulated data was plotted into a bar chart as shown in Figure 4.10.

Sample	Graphene	Hardness test value (HV)					
	wt.%	Test 1	Test 2	Test 3	Test 4	Test 5	Average
1	0.1	78.8	83.4	89.5	84.1	94.3	86.02
2	0.3	91.5	101	93.6	94	84.7	92.96
3	0.5	91.2	100	102	98.9	100	98.42

Table 4.1: Hardness testing result



According to Table 4.1, Sample 3 had the greatest hardness of 98.42HV with a graphene content of 0.5 wt. %, with fixed string time, pouring temperature, and cooling slope parameters of 10 minutes at 660°C, and 60° angle and 300 mm for the cooling slope parameters. According to M.S.Salleh et al. (2017), the A356 undergoes cooling slope casting with a Vickers hardness of 84.5HV. This prove that as the reinforcement were added in the aluminium alloy, the hardness of the aluminium alloy increses. Sample 3 with ideal settings exhibited a 16.47 % increase in hardness compared to A356 with cooling slope casting. Figure 4.10 demonstrates an increase in hardness with reinforcement and an improvement in hardness when reinforcement is increased. The hardness of A356+0.3 wt. % was 8.07 percent more than the hardness of A356+0.1 wt %. When the reinforcement is raised from 0.3 wt. % to 0.5 wt. %, the hardness of A356+0.3 wt. % increases by 5.87 %.

4.2.2 Tensile Test

The yield strength (0.2 % YS), ultimate tensile strength (UTS), and elongation (%) of the composites were determined by performing tensile testing on metal matrix composites in A356 with varying graphene wt. %. Figure 4.11 depicts the tensile specimen prior to fracture, whereas Figure 4.12 depicts the tensile specimen after fracture. The respective results are then presented in Table 4.2.



Figure 4.12: Tensile sample after fracture

Sample	Graphene wt.%	Ultimate Tensile Strength	Yield Strength (MPa)	Elongation (%)
		(MPa)		
1	0.1	223.33	139.54	6.14
2	0.3	237.19	143.44	10.04
3	0.5	241.63	145.02	11.62

Table 4.2: Tensile testing result

With the addition of reinforced nanoparticles, the tensile strength of A356 improved proportionately. Sample three has superior tensile qualities compared to samples one and two, as shown in figure 4.13. The Ultimate Tensile Strength (UTS), yield strength (YS), and elongation at fracture of A356 rise as the graphene content increases. According to a study conducted by H. Hanzam et al. (2019), the improvement of mechanical strength for PA and PB composites was primarily due to the combination of two major strengthening mechanisms for the alloy matrix, namely strengthening through complex microstructure evolution and precipitation of intermetallic phases. Load transfer, thermal mismatch dislocation, and the Orowan looping system were the reinforcement-induced strengthening mechanisms. Sample three has the greatest UTS with a value of 241.63MPa, which is an increase of 7.57% compared to sample one.



Figure 4.13: Ultimate tensile strength (MPa)

Additionally, sample three had the highest yield strength measurement of 145.02MPa and the highest elongation percentage of 11.62 percent. According to research done by Das, Samanta, Chattopadhyay, *et al.*, (2012), dendritic structure is to blame for the development of micro porosity as it forms a solid skeleton with the melt during solidification and decreases its fluidity, which in turn causes air pockets (micro porosity) in the solidified ingots and negatively affects their mechanical properties.



Figure 4.14: Yield Strength (MPa)



Figure 4.15: Percent of elongation

4.3 Summary

Based on the microstructural analysis, cooling slope casting process will produce nondendritic microstructure which able to enhance the mechanical properties of aluminium metal matrix composite. Moreover, the present of nano-graphene as reinforcement particles also help to improve the aluminium alloy in terms of hardness and tensile strength.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

On the basis of the data and discussion gained in Chapter 4, this chapter presents a conclusion of the experimental findings and some recommendations for future work enhancement. The results of the study are utilised to determine if the objective has been met. Ultimately, all research difficulties will be resolved, and the achievement of research objectives will be established.

5.1 Conclusion

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In this study, A356/Graphene composite feedstock was produced using cooling slope casting and mechanical stirring to prevent the formation of dendritic microstructure. Regarding the spherical microstructure of aluminium metal matrix composites manufactured by cooling slope casting, research and observation were conducted with varying nano-graphene contents. In addition, the signal-to-noise (S/N) ratio of the responses was analysed to quantify the differences in hardness and UTS. The conclusion can be summed up as follows, based on the examination of the acquired result:

 Cooling slope casting with mechanical stirring process result in, producing globular or spheroid microstructure.

- Forming of fine microstructure in A356/Graphene able to improve tensile properties and as the size of the grain size increase the hardness of the metal matrix composite will increases.
- iii) Intermetallic compounds were detected in the microstructure, and were observe by SEM and identification via XRD. Four main phases could be observe in XRD graph which is Mg_2Si , SiC, Al, and C.
- iv) The highest hardness and UTS values of 100.3HV and 241.63 MPa, respectively were obtained from sample three which contain 0.5 wt. % of graphene, with the optimum parameters of cooling slope which is 300mm length, 60° of inclined plate and 660°C of pouring temperature. Thus, the cooling slope casting process with the present of reinforcement helps to improve the mechanical properties of A356 alloy.

5.2 Recommendation

Regarding the reinforcement of nano-graphene within a metal matrix, there are a number of recommendations for future study that might be implemented to address a number of challenges and produce better and more desirable outcomes. Following are the recommendations:

1) Enhance the fluidity of the molten metal matrix composite when pouring it into the mould.

In this project, molten metal was poured onto the cooling slope without any flow requirements. This will prevent the molten metal from flowing smoothly into the mould and preventing the molten metal from entering the mould cavity in its entirety.

2) Produce moulds of varying sizes for casting.

The samples used in tensile tests required extensive material removal operations. EDM Wire-Cut is a time-intensive operation that generates a substantial amount of scrap. In order to save a great deal of time and avoid scrap, it is possible to produce moulds of varied sizes.

5.3 Sustainability Development

Sustainability development is essentially development that meets existing needs without compromising the ability of future generations to meet their own needs. Multiple interpretations exist for the concept of sustainable development. The heart of sustainable development is a strategy that seeks to balance multiple, and frequently competing, goals with an understanding of the environmental, social, and economic constraints that society faces.

In the automotive industry, the usage of aluminium alloys in this project has become an important sustainable strategy. This lightweight material has replaced heavy metals in automobiles because reducing the weight of automotive components can increase fuel economy and decrease carbon dioxide emissions. Substituting lightweight materials for heavier ones is the recommended method for increasing fuel efficiency without drastically altering the size or components of the vehicle.

5.4 Complexity

Throughout the studies, there were a few issues. A plunger was used to introduce the nano-graphene powder into the molten A356 alloys. Due to blockage in the plunger produced by the nano-graphene that was covered in aluminium foil, the insertion procedure occasionally did not go smoothly. As a result, the ball milling method had been suggested as a different approach for the composites' mixing procedure. Additionally, as the current methods for pouring molten metal matrix composites were insufficient, it is necessary to improve the flow ability when pouring molten metal on the cooling slope rail. Without knowledge of the molten metal's flow rate and the ideal positioning for the mould, the pouring procedure may result in the molten metal being unable to fill the mould cavity.

5.5 Life-long Learning

As a result of this study, cooling slope casting-made A356/Graphene composites had been created with improved mechanical properties in terms of hardness and tensile strength. In addition, cooling slope casting produces A356/Graphene with a distinct microstructure from conventional casting. Since they are lightweight, it might be used in a variety of production sectors, including aerospace and automotive. Studying the corrosion and wear characteristics of composites will also be beneficial for expanding the industries in which they can be used, reducing the use of natural resources, and creating a more environmentally friendly atmosphere.



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APPENDICES

Appendix A

Gantt chart of PSM 1

		Week																
No	Task	Semester 1 (October-March)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	PSM Title Registration																	
	Briefing of Title								-									
2	Selection																	
	Find Journals and																	
3	Reference Materials on																	
	the PSM Title																	
4	Define Objectives and																	
4	Problem Statement		V ave															
5	Identify Background	Maria	. 913	10.														
	and Scope of Study			9														
6	Carry Out for Literature				14				ak									
	Review								lre									
	Conduct on Findings			_					L B							eel		am
	Methodology of			-					ste		7					M		
7	Overall Process,	100					-		me							dy	-	Ial
	Methods, and	1							Sei							štu	4	
	Instruments				14		· ·	6	-p									
Q	Submission of Log	-			5		-		Ν	S		1	27					
0	Book to Supervisor									+*								
0	Preparation of UNIV	ER	SIT	I TE	EKI	IIK	AL	M/	LA'	YSI/	A M	EL/	AK/	λ				
"	Presentation PSM																	
10	Presentation for PSM																	
10	on Online Video								-									
11	Final Report PSM																	
11	Checked by Supervisor								-									
	Submission of PSM																	
12	Report to Supervisor																	
	and Examiner																	

Plan
Mid-Semester Break, Study Week, and Final Exam

Appendix B

Gantt chart of PSM 2

No				WEEK														
	Task			Semester 2 (Mar						arch -	Jun	e)						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Check the materials and																	
	chemical availability																	
2	Book the laboratories																	
	and prepare the																	
	materials																	
3	Discuss with supervisor																	
	about experiment																	
	preparations																	
4	Cutting raw materials																	
5	Into small pieces																	
5	weighning the cut															м		
	for casting	LAI	SIA	de.		_										eel		
6	Cooling slope casting			- 4						<u>~</u>						M	T	
v	process				2				_	rea						ıdy	kan	un
7	Cut the casting sample	•								e e e e e e e e e e e e e e e e e e e	-					Stı	E	EX8
	into required									ster			V /				nal	al I
	measurements									mes	-						Fi	Fin
8	Sample preparation for	0								Ser								
	testing	1								id-								
9	Hardness test	-	التاليب	4	4		2.	1	-	N	in.	ہر ہ	àu	0				
10	Optical microscopy	14	10)		- 10			· (;	2.0	V	a	/				
11	Tensile test	-								we			A.1.4	A				
12	SEM Analysis	P.C			: NI	NIP	AL	. WI	AL	ATO		VIEL	.Ar	A				
13	XRD Analysis																	
14	Submission of logbook																	
	to supervisor																	
15	Slide Preparation for																	
17																		
10	ΓΙΓΙΙ VIUEO Presentation																	
17	FICSCILLATION EVD II On A consign																	
1/	Submission of EVD											<u> </u>						
19	Sublitission OI Γ I Γ																	
	report																	

Plan
Mid-Semester Break, Study Week, and Final Exam