EFFECT OF FLY ASH CONTENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINIUM MATRIX COMPOSITES PROCESSED BY COOLING SLOPE CASTING

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This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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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 (Engineering Materials) (Hons). The member of the supervisory committee are as follow:

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(Profesor Madya Ir. Ts. Dr. Mohd Shukor Bin Salleh)

ABSTRAK

Komposit matriks logam (MMC) adalah sejenis bahan baru yang mempunyai potensi untuk digunakan dalam pelbagai aplikasi, termasuk dalam bidang angkasa, automotif, dan perlombongan. MMC dibuat dengan menggabungkan matriks logam dengan bahan penguatkuasaan ceramik. Fly ash, produk limbah daripada pembakaran arang batu. Ia adalah serbuk biji halus yang kaya dengan silika dan alumina. Fly ash atau abu terbang telah terbukti menjadi bahan penguatkuasaan yang menjanjikan untuk aluminium logam matriks komposit (MMC). Walau bagaimanapun, kesan kandungan fly ash pada mikrostruktur dan sifat mekanikal alumunium MMC yang diproses oleh pencairan pinggiran sejuk masih tidak jelas. Kajian ini akan menyiasat kesan menambahkan abu terbang kepada aloi aluminium MMC yang dihasilkan oleh pencairan lereng sejuk. Penyelidikan ini akan menambah 4, 8 dan 12 peratus berat debu terbang kepada aloi aluminium dan kemudian aloi alumunium mengalir dengan debu terbang, yang dicampur pada 350 rpm selama 5 minit dan ditumpahkan ke dalam mold pada suhu 800 ° C. Kemudian, sampel akan diuji untuk kekerasan, kekuatan tegangan, dan kepadatan untuk menyiasat karakterisasi. Ia dijangka bahawa penambahan abu terbang akan meningkatkan sifat mekanikal dan fizikal aloi aluminium MMC. Ini kerana partikel abu terbang boleh bertindak sebagai penghalang kepada pergerakan dislokasi dan menyempurnakan saiz bijirin matriks aluminium, yang kedua-duanya membawa kepada peningkatan kekuatan. Selain itu, debu terbang kurang padat daripada aluminium, jadi menambah debu terbang kepada MMC boleh mengurangkan berat keseluruhan mereka. Hasil kajian ini boleh membawa kepada pembangunan MMC baru dan ditingkatkan untuk pelbagai aplikasi.

ABSTRACT

Metal matrix composites (MMC) are a new type of material that has the potential to be used in a wide range of applications, including aerospace, automotive, and mining. MMC are made by combining a metal matrix with a ceramic reinforcement material. Fly ash, a waste product from coal combustion. It is a fine-grained powder that is rich in silica and alumina. Fly ash has been shown to be a promising reinforcement material for aluminium metal matrix composite (MMC). However, the effect of fly ash content on the microstructure and mechanical properties of aluminium MMC processed by cooling slope casting is still unclear. This study will investigate the effect of adding fly ash to aluminium alloy MMC produced by cooling slope casting. The research will add 4, 8, and 12 weight percent fly ash to the aluminium alloy and then the aluminium alloy melts with fly ash, which is stirred at 350 rpm for 5 minutes and poured into the mold at a temperature of 800°C. Then, the specimen will be test for hardness, tensile strength, and density to investigate its characterization. It is expected that the addition of fly ash will improve the mechanical and physical properties of the aluminium alloy MMC. This is because fly ash particles can act as barriers to dislocation motion and refine the grain size of the aluminium matrix, both of which lead to an increase in strength. Additionally, fly ash is less dense than aluminium, so adding fly ash to the MMC could reduce their overall weight. The results of this study could lead to the development of new and improved MMC for a variety of applications.

DEDICATION

I am dedicating this work to my parents Sandy Anak Ating and Elizabeth Purin Anak Grambeh, who always inspire and support me with their boundless love and encouragement to endeavour in achieving a success in everything I went through.

To my supervisor, Profesor Madya Ir. Ts. Dr. Mohd Shukor Bin Salleh, panels, family and all of my friends and colleagues, without whom none of my success would be possible.

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This achievement is a testament to the collective strength of this incredible team. To each and every one of you, my heartfelt gratitude. Together, we have scaled mountains and crossed oceans, and in the end, we reached the summit, hand in hand.

Thank you.

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LIST OF ABBREVIATIONS

Al_2O_3	-	Aluminium Oxide
ASTM	-	American Society for Testing and Materials
AMCs	-	Aluminium Matrix Composites
CO_2	-	Carbon Dioxide
CuO	-	Copper Oxide
DoE	-	Design of Experiment
Fe_2O_3	-	Iron Oxide
FTIR	-	Fourier transform infrared
K_2O	-	Potassium Oxide
MgO	-	Magnesium Oxide
MMCs	-	Metal Matrix Composites
OM	-	Optical Microscopy
RSM	-	Response Surface Method
SEM	-	Scanning Electron Microscopy
SiO_2	-	Silicon Dioxide
TiO_2	-	Titanium Dioxide
UTM	-	Universal Testing Machine
XRD	-	X-Ray Diffraction

LIST OF SYMBOLS

%	-	Percentage
°C	-	Degree Celsius
HV	-	Vickers Hardness
Mm	-	Millimetre
Rpm	-	Rotation Per Minute
wt. %	-	Weight Percentage

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Advanced materials are required in modern manufacturing. We require components that include enhanced lightweight properties, increased strength, and superior resistance to wear, surpassing all previous standards. The project challenges the limits of conventional materials and casting techniques. Conventional casting frequently encounters problems like as porosity, non-uniform microstructures, and variations in final characteristics. These constraints hinder the advancement of high-performance materials necessary for rigorous applications in industries such as aerospace, automotive, and construction.

Fly ash, a residual substance resulting from the combustion of coal, is emerging as a promising alternative. It offers both economic and technical benefits. Firstly, the plentiful supply of coal from coal-fired power plants worldwide provides a conveniently accessible and renewable resource. Furthermore, its distinctive chemical and physical characteristics render it a highly attractive contender for augmenting the mechanical capabilities of established materials such as aluminium. (ASTM, 2020) Fly ash functions as a reinforcing ingredient, enhancing the strength, rigidity, and durability of aluminium matrix composites (AMCs). This creates opportunities for the development of materials that can fulfil the exacting demands of contemporary technical applications.

Although previous studies have revealed the prospective capacity of fly ash as a strengthening agent for AMCs, there are still numerous crucial issues that have not been investigated. (Asa et al., 2020) Further work is required to determine the exact influence of fly ash content on both the microstructure and mechanical properties of these composites. Furthermore, the task of optimising the cooling slope casting process to get uniform and controllable characteristics poses a considerable problem. (Yadav & Chakrabarty, 2020) The study intends to fully exploit the potential of this innovative material technology by thoroughly analysing the complex correlation between fly ash concentration, microstructure, and mechanical properties in the context of cooling slope casting. The discoveries are crucial for facilitating the development of enhanced AMCs, which will enable a wide range of innovative applications.

1.2 PROBLEM STATEMENT

The traditional casting methods often used in industrial manufacturing face numerous restrictions that present significant challenges to achieving components of the highest quality. A major obstacle is the presence of porosity in cast materials, which undermines the structural integrity and obstructs the achievement of desired mechanical qualities. Moreover, the inherent incapacity to attain consistent microstructures worsens these problems, leading to components with variable performance and reliability. An additional notable limitation is the absence of meticulous control over material properties during the casting procedure, impeding producers from customizing materials to fulfil precise application demands.(Bharambe et al., 2023) Given these constraints, it is imperative to revamp conventional casting techniques in order to improve the mechanical characteristics of materials and facilitate the manufacturing of components capable of enduring the demanding requirements of contemporary industrial and construction uses.

To tackle these urgent difficulties, a potentially effective approach is to investigate the integration of fly ash as a strengthening agent in the casting process. Fly ash, a residue produced by the burning of coal, has attracted interest due to its ability to improve the mechanical properties of materials. (Xiong et al., 2019) Nevertheless, the efficacy of utilizing fly ash reinforcement has not been thoroughly investigated, and its potential for addressing the limitations of traditional casting methods is not yet comprehensively appreciated. The current problem statement highlights the need to examine the impact of fly ash on enhancing materials and enhancing their mechanical qualities.

1.3 OBJECTIVE OF STUDY

The objectives are as follows:

(a) To investigate the effect of fly ash content on the mechanical properties of aluminum matrix composite processed by cooling slope casting.

(b) To analyze the microstructure of the fly ash content in the aluminum matrix composite.

(c) To investigate the mechanical properties of the fly ash reinforced aluminum matrix composite after T6 heat treatment.

1.4 SCOPE OF STUDY

This study focuses on the field of material science and examines the possibility of using fly ash as a strengthening agent in the creation of a new type of aluminum matrix composite (AMC). The study seeks to investigate the impact of systematically modifying the fly ash content on the microstructure and mechanical properties of this new material.

The examination of microstructure is central to this topic. Analyze the grain size, distribution, and shape of the composite to gain valuable knowledge about the complex relationship between fly ash particles and the aluminum matrix. This knowledge is crucial for understanding the fundamental mechanisms that control the strength, ductility, and wear resistance of the end material. (Md Ali et al., 2021) The microstructural landscape will be carefully analyzed using techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD) to investigate the effects of different fly ash content on its form and distribution. (Yadav & Chakrabarty, 2020)

Expanding beyond the field of microscopic analysis, the study delves into the arena of evaluating mechanical properties. The study aims to determine the impact of fly ash content on important performance metrics such as tensile strength, yield strength, and hardness of the AMCs. This will be achieved by rigorous testing and analysis. Achieving the highest possible desired qualities while maintaining ductility is a crucial goal, and it involves determining the ideal fly ash content. (Xiong et al., 2019) This optimization approach will facilitate the development of AMCs with customized mechanical properties for specific applications.

Although the study utilizes a targeted aluminum alloy and cooling slope casting technique to establish a clear experimental framework, it acknowledges the inherent diversity in fly ash sources and qualities. The intricacy of the real-world situation will be tackled by integrating statistical study of the fly ash properties and their impact on the ultimate properties of the AMCs. This guarantees that the acquired results are statistically sound and have practical significance for widespread manufacturing utilizing various fly ash sources. (Gunawan et al., 2020)

This project represents a significant milestone in the process of fully harnessing the capabilities of fly ash-reinforced AMCs. The study establishes a foundation for future progress in the field by clarifying the complex connection between fly ash content, microstructure, and mechanical qualities in the controlled and realistic conditions of cooling slope casting. The optimized AMCs produced in this study have the potential to significantly transform many industries, including construction, automotive, aerospace, and defense. These industries have an increasing demand for lightweight and high-performance materials.

1.5 IMPORTANT OF STUDY

The study of fly ash-reinforced aluminium matrix composites (AMCs) is of great scientific and practical importance. Firstly, it investigates the possibilities of fly ash, which is a commonly accessible by-product, as a sustainable and cost-efficient reinforcing ingredient. (Xiong et al., 2019) Gaining insight into its influence on the microstructure and mechanical properties allows for the customisation of AMCs to achieve specific strengths, ductility, and wear resistance for a wide range of applications. Furthermore, this study aims to connect scientific investigation with practical application by specifically examining a casting technique and taking into account the diversity of fly ash. (Gunawan et al., 2020)

This guarantees that the discoveries be converted into economically feasible Advanced Materials Composites (AMCs), specifically targeting the increasing need for high-performance, lightweight materials in diverse industries. This research enhances our comprehension of the complex mechanisms present in these composites, so providing vital insights to the field of material science. (Vinoth Babu et al., 2022) It also serves as a catalyst for subsequent advancements and enables the realisation of the complete capabilities of fly ash in sustainable material innovation.

1.6 ORGANIZATION OF THE REPORT

Chapter 1 of this report provides an overview of the study and title introduction. This chapter provides an overview of the study's context and presents the problem statement. Subsequently, the study outlines its objectives, which are the specific goals to be accomplished, and the scope, which delimits the specific area of focus.

1.7 SUMMARY

This chapter clarify the background of study and the problem statement. The target, important of study and scope of this study are further mentioned in which the purpose of this project is to determine the fly ash content on the microstructure and mechanical properties of aluminium matrix composite processed by cooling slope casting.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

The persistent need for materials that are both lightweight and durable in contemporary engineering drives the investigation into unusual alternatives. Aluminium matrix composites (AMCs) that are strengthened with fly ash are becoming interesting competitors because to their combination of cost-effectiveness, sustainable resource utilisation, and the possibility of substantial performance improvements. (Gunawan et al., 2020) Nevertheless, despite a significant increase in study endeavours, some essential facets of this intriguing material combination remain obscured by uncertainty.

This literature review undertakes a thorough investigation, with the goal of shedding light on the intricate relationship between the amount of fly ash, the microstructure, and the mechanical properties of AMCs produced using the cooling slope casting method.

The experiment begins in the microstructural realm, where the impact of altering fly ash content on grain size, distribution, morphology, and interfacial interactions within the AMC matrix is explored. The examination at a microscopic level is crucial for revealing the underlying principles that determine the observed properties of strength, ductility, and wear resistance in these composites. Comprehending the complex movement of fly ash particles within the aluminium matrix is crucial for fully harnessing their capabilities in various applications. (da Motta et al., 2023)

Subsequently, the attention is directed into the domain of measurable performance, where thorough analysis is conducted on previous studies regarding the tensile strength, yield strength, hardness, and other crucial mechanical characteristics of fly ash-reinforced AMCs. This research enables the discovery of the optimal fly ash content, which refers to the ideal point that maximises desired performance attributes while maintaining the integrity of other essential elements. (Gunawan et al., 2020) Exploring the realm of mechanical expertise is essential for advancing the development of AMCs that can effectively fulfil the rigorous requirements of contemporary engineering applications.

Ultimately, armed with the knowledge acquired from previous research, the path for future progress is established. Through the identification of knowledge gaps and limits in the existing body of research, potential areas for further exploration are determined. This undertaking sets the stage for future attempts to enhance and investigate these innovative materials, pushing the limits of what can be achieved and unlocking their complete potential for a variety of uses.

An in-depth analysis of the complex relationship between the amount of fly ash, the microstructure, and the mechanical qualities is of great importance when considering the process of cooling slope casting. This comprehensive literature review attempts to clarify the way toward unlocking the great potential of fly ash-reinforced AMCs, contributing to the development of sustainable and high-performance materials for the future.

2.2 MATERIAL CHARACTERISTICS

The present research investigates the complex relationship that exists between the microstructure, mechanical properties, fly ash content, and cooling slope casting-produced aluminium matrix composites (AMCs). The work uses advanced imaging techniques such as SEM and XRD to examine the microscopic structures within the composites, investigating the interactions between fly ash particles and the aluminium matrix. In addition, it measures mechanical performance by conducting tests to determine tensile strength, yield strength, and hardness. Recognizing the heterogeneity in fly ash and casting processes, the study applies extensive fly ash characterization and robust statistical analysis to assure statistically meaningful and real-world applicable conclusions. In essence, this all-encompassing strategy seeks to fully use the capabilities of fly ash-reinforced AMCs in order to create sustainable and high-performance materials.

2.2.1 FLY ASH

Fly ash is a finely textured, non-flammable powder that is produced as a by-product of burning coal in power plants. Previously regarded as a byproduct with no value, this substance has experienced a remarkable change in recent times, being utilised in various applications due to its distinct characteristics and positive impact on the environment. (ASTM, 2020) The fly ash to be utilised in this experiment will be sourced from YTL Power Plant located in Klang.

2.2.1.1 CHEMICAL COMPOSITION

Fly ash is predominantly composed of spherical, translucent particles that are produced as a result of the incomplete combustion of coal. The composition of coal can vary depending on the source and conditions of combustion. However, it generally consists of key elements such as silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3). In addition, there may be minor quantities of calcium oxide (CaO), magnesium oxide (MgO), and sulphur trioxide (SO_3).(ASTM, 2020) (Xiong et al., 2019)

	Chemical compositions (%)							
Materials	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**K_2O**	**others**
Fly Ash	57.95	28.15	4.75	0.93	3.74	1.73	0.62	2.13
Alumina	0.018	99.70	0.02	0.006	-	-	-	0.26

Table 2-1 Typical Chemical Compositional of Fly Ash *(Arifin et al., 2018)*

Fly ash possesses pozzolanic qualities due to its high concentration of silicon dioxide, which is a key constituent of glass and cement. When there is moisture and calcium hydroxide present, fly ash undergoes a reaction to produce calcium silicate hydrates. (Arifin et al., 2018) This reaction leads to substantial increases in strength and improved durability in concrete mixtures. In addition, the use of aluminium oxide enhances the general ability to bind, whereas iron oxide can impact both colour and specific mechanical characteristics. The classification of fly ash into Classes F and C is determined by the changes in its composition, namely the amount of CaO it contains. Each class has unique advantages and limits that are specific to certain uses. (ASTM, 2020)

Although fly ash is highly effective in improving the performance of concrete, its uses go beyond this specific area. The pozzolanic qualities of this substance provide advantages for various construction materials such as bricks, tiles, and precast items. Due to its small particle size and its capacity to act as a filler, it is highly beneficial in the production of paints, adhesives, and as a substitute for a portion of cement. In addition, research efforts investigate the potential of fly ash in composites, geopolymers, and agricultural uses. (Xiong et al., 2019)

2.2.1.2 FORMATION AND PHYSICAL CHARACTERISTICS

Fly ash travels all the way from the blazing core of a power plant. Insufficient burning takes place when finely ground coal is exposed to elevated temperatures ranging from 800 to 1500°C. (Al-Shmaisani et al., 2022) This procedure involves the liquefaction of the inorganic minerals present in coal, resulting in the formation of molten droplets that quickly evaporate as a result of the high temperature. These droplets undergo a transformation and become small, smooth particles that are suspended in the flue gas. These particles include the essential elements of the coal's mineral composition. Nevertheless, the highly unstable components such as sulphur and mercury tend to evaporate more readily during this process, hence impacting the ultimate chemical composition of the fly ash.

The flue gas containing these newly formed ash particles is subsequently sent via advanced dust collectors. The fate of the particles is determined by their size and weight.

Particles that are heavier and larger settle down and are classified as bottom ash, while the particles that are finer and lighter stay in the air and eventually form the fly ash. Fly ash can be further categorised depending on its calcium oxide (CaO) content. This classification divides fly ash into two primary groups: Class F, which has a low CaO content (<10%), and Class C, which has higher CaO levels (10-20%). (Asa et al., 2020) The differentiation between various types of fly ash is essential in assessing its appropriateness for diverse uses.

Fly ash is characterised by its exceptionally fine particle size, often falling within the range of 10 to 100 microns. Fly ash possesses outstanding packing qualities due to its minute size, which is substantially smaller than that of cement. This attribute boosts its function as a filler substance, efficiently sealing gaps and empty spaces within concrete mixtures, resulting in denser and stronger buildings. (Vijaybabu et al., 2019)

The little size of fly ash particles results in an exceptionally large surface area. The large surface area of fly ash allows for increased chemical interactions, greatly improving its reactivity. Within the realm of concrete, this increased reactivity plays a vital role in the pozzolanic activity of fly ash. Upon exposure to moisture and the calcium hydroxide generated during the process of cement hydration, fly ash quickly engages in chemical reactions, resulting in the formation of calcium silicate hydrates. These hydrates play a crucial role in augmenting the strength and longevity of concrete structures.(Bharambe et al., 2023; Kumar Yadav et al., 2022)

The physical characteristics of fly ash encompass more than just its particle size and surface area. The colour of the object might range from pale grey to tan or even deep brown, mostly determined by the amount of iron oxide present. Elevated concentrations of iron oxide typically led to a more intense and deeper hue. Moreover, fly ash has a lower density compared to cement, which makes it a beneficial component in applications that require reduced weight. (Asa et al., 2020) By partially substituting cement in concrete mixtures, fly ash helps to the creation of lighter structures, which can potentially yield advantages in building design and construction. (R. Yadav et al., 2023a)

An in-depth exploration of the physical properties of fly ash paints provides a more comprehensive understanding of their potential. The material's small size, large surface area, and distinct chemical composition all contribute to its remarkable features, which make it very desirable for many applications. To fully exploit the capabilities of fly ash and develop sustainable and novel material solutions, it is crucial to comprehend its physical properties. This includes improving the performance of concrete and investigating its applications in composites and geopolymers. (Tanvar et al., 2018)

Fly ash exhibits a diverse colour palette, spanning from pale grey to tan or even deep brown, which adds to its overall fascination. The iron oxide concentration predominantly influences this variance, with larger amounts resulting in a deeper tint. The density of fly ash is lower than that of cement, making it an important factor. Using fly ash as a partial substitute result in lighter concrete mixtures, which is advantageous for weight-sensitive applications. (Prasat & Subramanian, 2013)

The chemical makeup of fly ash is intricately determined by the origin of the coal and the conditions under which it was burned. The composition of fly ash is primarily influenced by silicon dioxide, aluminium oxide, iron oxide, calcium oxide, magnesium oxide, and sulphur trioxide. Each of these components plays a crucial role in determining the pozzolanic qualities and applicability of the fly ash for various applications. (Asa et al., 2020)

Gaining knowledge about the development and tangible properties of fly ash is not merely a theoretical endeavour. It facilitates the utilisation of its distinctive characteristics for sustainable construction techniques and other applications. Fly ash's pozzolanic properties, along with its positive impact on the environment by lowering CO_2 emissions and landfill waste, make it a promising solution for a more sustainable future. (Vinoth Babu et al., 2022a)(Cheng et al., 2023) By exploring its complexities, we may fully harness its capabilities and make a meaningful contribution to a future where trash is repurposed, and resources are utilised optimally.

2.2.1.3 ENVIRONMENTAL ISSUES

The use of fly ash as a resource has significant environmental advantages. It diverts a major waste stream from landfills, decreasing landfilling costs and environmental footprints.(Asa et al., 2020) Moreover, fly ash serves as a partial substitute for cement in concrete, resulting in reduced CO_2 emissions linked to cement manufacturing. (Cheng et al., 2023) The pozzolanic characteristic of fly ash also improves the long-term durability of concrete, resulting to decreased maintenance needs and less resource use over its lifespan.

2.2.2 METAL MATRIX COMPOSITES

Metal matrix composites (MMCs), wonders of material science, are created when the worlds of metals and ceramics combine. These masterfully designed materials effortlessly combine the formidable durability and heat conduction of metals with the remarkable rigidity and abrasion resistance of ceramic reinforcements, resulting in a harmonious blend of improved characteristics. (Aboudi, 2019)(Prasat & Subramanian, 2013)

Envision a substance that merges the durability of aluminium with the capacity for lightness seen in carbon fibres, or the ability to disperse heat exhibited by copper combined with the resilience to wear of silicon carbide. (Wang et al., 2020) These are the potentialities unleashed by MMCs. These composites excel in challenging aerospace applications, high-performance engines, and state-of-the-art tools since they continuously push the limits of material performance.

Moreover, the appeal of MMCs beyond their remarkable characteristics. Their capacity to be customised for individual applications adds an additional level of fascination. Engineers have the ability to create Metal Matrix Composites (MMCs) that are very effective in different conditions and can meet a wide range of requirements by adjusting the kind and quantity of reinforcement, as well as the production method. This adaptability enhances their potential in diverse sectors. (Gunawan et al., 2020)

Exploring farther into the realm of MMCs uncovers a mesmerising fabric crafted from many forms of reinforcements, such as fibres, whiskers, and particles. Each reinforcement, from the sophisticated allure of carbon fibres to the robust resilience of silicon carbide, possesses its own distinct benefit. (Mavhungu et al., 2017) Understanding the complex interplay between these reinforcements and the metal matrix is crucial for harnessing the complete capabilities of these advanced materials.

Ultimately, metal matrix composites serve as a monument to the remarkable human capacity for manipulating materials to suit our specific requirements. With their remarkable qualities, versatility, and seemingly limitless potential, these materials are at the forefront of material science. They have the potential to revolutionise various industries and open up new possibilities for a future where lightweight meets durability and performance beyond conventional constraints.(Arjunraj et al., 2023)

2.2.2.1 DESIGNATION OF METAL MATRIX

The designation of the metal matrix in an aluminium matrix composite (AMC) is of utmost importance, as it significantly impacts the processing, microstructure, and ultimately, the mechanical properties of the composite. The A356 aluminium alloy has been selected as the metal matrix for this inquiry due to its impressive mix of desirable characteristics and also its availability as we acquire the alloy from a powerplant in the vicinity. This choice allows for a thorough exploration of the impact of fly ash content on the microstructure and mechanical performance of AMCs produced using cooling slope casting. Table 2 below presents the use of several waste resources in the production of aluminium-based composite material. It was clear from the historical material that one thing had been previously comprehended. Several researchers have employed various forms of reinforcement to significantly improve the mechanical characteristics of aluminium. (Yadav et al., 2023)

Metal matrix composite (MMCs)	Reinforcement	Properties observed
Al-6061	Rice husk ash	Micro structure, thermal behavior
Al-hybrid composites	Sugarcane bagasse ash/SiC	Impact strength, hardness, tensile strength
Al-composite	Coconut shell particle	Tensile strength, hardness, wear
Al-composite	Steel and graphite particle	Ductile, hardness, tensile strength, toughness
Al-MMCs	Fly ash	Tensile strength, wear, toughness
Al-composite	Carbonized coconut shell	Tensile strength, hardness
Al-MMCs	Hot forging press of chip	Density, hardness
Al-MMCs	Mines waste	Cutting force, wear

Table 2-2 Utilization of Various Waste Materials in Preparation of Aluminium-based Composite Material

The classification system for aluminium alloys adheres to a standardised methodology. A356 represents:

A: Signifies a superior quality variant in contrast to the fundamental alloy.

3: Silicon is the principal alloying ingredient, constituting around 7% of the composition. It significantly improves fluidity, castability, and strength.

5: Signifies the existence of copper, approximately 0.3%, which enhances strength and hardness.

6: Magnesium is commonly added in a concentration of 0.2-0.3% to improve ductility, corrosion resistance, and castability.

The chemical composition of A365 aluminium alloy given in Table 2.2-2below.

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Pb	Sn	Al
A356	6.5	0.35	0.20	0.10	0.45	0.10	0.10	0.10	0.20	0.10	0.05	Bal

Table 2-3 Chemical Composition of A356 alloy (wt%) (Alhawari et al., 2013)

In addition to its conventional designation, A356 presents distinct advantages for this research: A356 exhibits exceptional castability, characterised by its remarkable fluidity and minimal shrinkage, making it very suitable for the cooling slope casting technique. This guarantees precise specimen geometry and minimises casting errors that may impact the results. (Md Ali et al., 2021)(Praharaj et al., 2014)

2.2.2.2 PROPERTIES OF A356

The choice of the metal matrix is crucial in the complex fabric of aluminium matrix composites (AMCs). The A356 aluminium alloy proves to be an excellent choice for this experiment on the impact of fly ash content on microstructure and mechanical properties. The distinctive combination of characteristics provides a compelling foundation for exploring the captivating interaction between fly ash reinforcement and AMC performance.

An essential factor of A356 resides in its remarkable castability. The chosen cooling slope casting method is well aligned with this property, which is characterised by fluidity and low shrinkage. A356 effortlessly occupies intricate mould holes, hence minimising the occurrence of casting flaws that may possibly distort experimental findings. (Mavhungu et al., 2017) This guarantees the production of precise and dependable specimen shapes, which are crucial for obtaining valid and consistent data.

In addition to its castability, A356 possesses a well-balanced array of mechanical qualities. The inclusion of silicon as the predominant alloying component adds to heightened strength and fluidity, whereas copper provides supplementary rigidity and durability. Magnesium, an additional vital component, enhances the corrosion resistance and additionally impacts the castability. The inherent robustness of A356 provides a reliable foundation for investigating the impact of different fly ash concentrations on key mechanical properties such as tensile strength, yield strength, and wear resistance. (Yadav et al., 2023) Through careful observation of the interaction between fly ash reinforcement and the existing mechanical profile, researchers can acquire useful insights into the wide range of uses that these composites may have.

Moreover, the selection of A356 is driven by its accessibility and prevalence in the research setting. Convenient availability of the material enables seamless acquisition and encourages prospective collaboration with faculty members well-versed in its handling and characteristics. The collaborative nature of this setting enhances the research endeavour by granting access to specialised information and expertise, so ultimately leading to a study that is completer and more insightful.

Conclusively, the A356 aluminium alloy, renowned for its remarkable castability, advantageous mechanical properties, and convenient local availability, emerges as an ideal candidate for investigating the impact of fly ash content on the microstructure and mechanical performance of AMCs produced through cooling slope casting. This thoughtfully selected metal matrix establishes the foundation for a methodically planned research endeavour, opening up possibilities for significant findings and future breakthroughs in the field of high-performance and environmentally friendly composite materials.

2.3 ALUMINIUM MATRIX COMPOSITES (AMCs)

This study focuses on aluminium matrix composites (AMCs), which are created by combining the A356 aluminium alloy with fly ash. These meticulously designed materials effectively combine the durable strength and heat conduction of aluminium with the rigidity and ability to withstand wear of fly ash, paving the way for improved performance and sustainability. (Md Ali et al., 2021)(Aboudi, 2019)

A356, the selected metal matrix, possesses its own inherent strengths. The remarkable castability of this material guarantees the creation of precise and dependable specimen shapes, which are crucial for conducting a meaningful investigation. The mechanical profile of this system is well-balanced, thanks to the inclusion of silicon, copper, and magnesium. This combination creates a firm foundation for studying the impact of fly ash reinforcement. Researchers can effectively monitor how changes in fly ash content precisely influence important characteristics like as tensile strength and yield strength. (Vinoth Babu et al., 2022)

Fly ash, on the other hand, offers a promising prospect for the advancement of sustainable composite materials. This byproduct of coal combustion not only has a beneficial second life in AMCs, but also plays a role in reducing landfill trash and perhaps lowering CO_2 emissions in comparison to typical composite reinforcements.(Xiong et al., 2019) The chemical composition of this material, which mainly comprises silicon dioxide, aluminium oxide, and iron oxide, possesses distinctive pozzolanic qualities when mixed with the A356 matrix.(Arifin et al., 2018) The pozzolanic reactions additionally bolster the robustness and resilience of the AMCs, resulting in potentially extended lifespans and diminished maintenance requirements.

Furthermore, the precise variety and quantity of fly ash utilised in this investigation are crucial in revealing unique characteristics in the producing AMCs. By adjusting the fly ash content and investigating various particle sizes or morphologies, researchers have the ability to precisely optimise the material's performance for certain applications. (Arifin et al., 2018) This paves the way for the creation of lightweight yet durable AMCs that are well-suited for a wide range of industries, including automotive and aerospace sectors, as well as construction materials and tools. (Md Ali et al., 2021)(Mavhungu et al., 2017)

Ultimately, the distinctive collaboration between A356 and fly ash in this investigation sets the stage for the development of top-notch, environmentally friendly AMCs. Through the utilisation of the distinct capabilities of these materials and the examination of the interaction between their characteristics, researchers possess the ability to uncover a novel assortment of composites that effectively combine performance and environmental conscientiousness(Md Ali et al., 2021). This captivating investigation into the realm of AMCs assures to reveal intriguing prospects for the advancement of material science and sustainable engineering.

2.4 COOLING SLOPE CASTING

The fabrication technique employed in this study on fly ash-reinforced aluminium matrix composites (AMCs) is of utmost importance in determining the ultimate properties of these materials. The technique of cooling slope casting is selected because to its combination of simplicity, control, and possibility for scalability, making it an appealing choice. The cooling slope inclined plate was made by stainless steel having 90mm width, and with 60° tilt angle. (Salleh et al., n.d.)

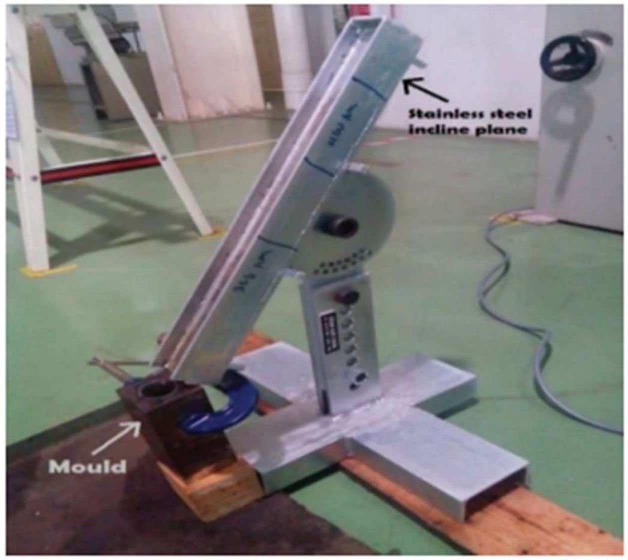

Figure 2-1 Cooling slope casting apparatus (Salleh et al., n.d.)

The fundamental notion of cooling slope casting is straightforward. The A356 aluminium alloy, in its molten state, is placed onto a moderately inclined slope that is regulated for temperature. This alloy serves as the metal matrix for the AMCs. The controlled slope of the incline generates a temperature gradient along the trajectory of the flowing metal, resulting in a gradual solidification process that initiates from the colder end and advances towards the warmer section. The gradual and controlled removal of heat in this process promotes the development of smaller grain sizes in the resultant composite and has the ability to affect the distribution of fly ash particles.(Li et al., 2023) (Safian et al., n.d.)

This study is supported by several significant benefits that justify the selection of cooling slope casting. One of it is this technique is easily adjustable and affordable for research settings. (Salleh et al., n.d.) The uncomplicated simplicity of the process allows for the fast creation of many samples with different amounts of fly ash, which enables a thorough examination of its effects on the AMCs. (Xiong et al., 2019)(Sunil Kumar et al., 2019)

Besides, the natural temperature difference inside the casting setup allows for precise control of the solidification process. This adjustable characteristic enables researchers to potentially customise the microstructure of the AMCs and impact the interaction between the A356 matrix and the fly ash reinforcement. Although cooling slope casting is mostly used in research environments, technique shows potential for being adapted to greater production volumes. This paves the way for wider implementation of fly ash-reinforced AMCs in future industrial applications.(Cheng et al., 2023) (Wang et al., 2020)

To conclude, cooling slope casting is a suitable approach for this inquiry because to its simplicity, affordability, and capacity to manage solidification. By offering a regulated fabrication platform for fly ash-reinforced AMCs, it enables researchers to further investigate the complex connection between fly ash content, microstructure, and mechanical performance. This comprehension lays the foundation for the advancement of high efficiency, enduring composite materials with the capacity to transform various industries.

2.4.1 PARAMETERS OF COOLING SLOPE CASTING

During this study, three parameters stand out as critical to understanding how fly ash content affects aluminium matrix composites (AMCs) made via cooling slope casting. First of all is pouring temperature. This parameter determines the initial thermal energy of the A356 aluminium alloy in its molten state prior to encountering the temperature differential on the slope. Pouring temperature of 630°C, 640°C, 650°C and 660°C were selected in this study. (Safian et al., n.d.) Modulating the pouring temperature has an impact on the rate at which solidification occurs and can potentially alter the size and distribution of fly ash particles within the composite. Increased pouring temperatures typically result in a delayed solidification process and the formation of larger grains, whereas lower temperatures accelerate solidification and can lead to the formation of smaller grains. By examining various pouring temperatures, one may analyse how they affect the microstructure and mechanical properties of the produced AMCs.

The cooling slope length refers to the distance that the molten metal travels when encountering a temperature gradient. The cooling slope lengths were marked at 200mm, 300mm and 400mm. This distance has influence in the duration and extent of the directional heat extraction. (Salleh et al., n.d.) A greater incline of the slope results in a more gradual change in temperature and may encourage a slower and more regulated process of solidification. In contrast, a slope that is shorter results in a more pronounced temperature gradient and the possibility of quicker solidification. By systematically altering the length of the cooling slope, one may evaluate its impact on the microstructure and mechanical characteristics of the AMCs, thereby customising them for specific purposes.

This is the important aspect of the study, as varying proportions of fly ash will undoubtedly affect the characteristics of the final AMCs. Fly ash (0, 4, 8 and 12 wt%) will be used in this experiment as this are the research gap. (Vinoth Babu et al., 2022) (Arifin et al., 2018) The interplay between the fly ash particles and the A356 matrix is pivotal in determining the microstructure, mechanical strength, wear resistance, and other essential features of the composite. By examining different levels of fly ash content, one can assess its impact on these factors and potentially enhance the performance of the composite to meet specified criteria. (Xiong et al., 2019)

Through a comprehensive investigation of these three interconnected parameters, one can gain insight into the intriguing interaction between fly ash content, microstructure, and mechanical performance in advanced matrix composites (AMCs). Ensure to select a diverse set of values for each parameter, taking into account your research goals and the constraints of your equipment. Moreover, it is imperative to maintain uniform casting conditions and perform duplicate tests for every set of parameters in order to acquire dependable and statistically meaningful outcomes. (Safian et al., n.d.)

2.4.2 MICROSTRUCTURES AND MECHANICAL PROPERTIES OF AMCs PROCESSED THROUGH COOLING SLOPE CASTING

The fly ash content, which ranges from 0 to 12 wt%, is a crucial factor that will undeniably impact the ultimate properties of the AMCs. The interplay between these particles and the A356 matrix is vital in determining key properties like as microstructure, mechanical strength, wear resistance, and other essential characteristics. Through a systematic analysis of varying degrees of fly ash concentration, researchers may evaluate its influence on these aspects and perhaps enhance the performance of the composite to satisfy precise standards. (Kumar Yadav et al., 2022) Increased fly ash content can result in enhanced dispersion of particles as a result of better interaction with molten aluminium at elevated pouring temperatures. However, it may also lead to particle clustering at higher concentrations, which can negatively affect uniformity and characteristics. (Vinoth Babu et al., 2022)

Pouring temperature determines the initial thermal energy of the A356 alloy in its molten state prior to encountering the temperature differential on the slope. Different pouring temperatures (630°C, 640°C, and 650°C) affect the rate at which the material solidifies and may change the size and arrangement of fly ash particles in the composite. Elevated temperatures often lead to reduced solidification rates and the possibility of larger grain sizes, whilst lower temperatures promote accelerated solidification and the possibility of smaller grain sizes. (Salleh et al., n.d.) Analysing the impact of various pouring temperatures on the microstructure and mechanical properties of the created AMCs enables to customise them for specific applications.

The length of the cooling slope, which refers to the distance that the molten metal travels when it encounters a temperature differential (specifically 200mm, 300mm, and 400mm in this study), affects both the duration and intensity of directional heat extraction. (Safian et al., n.d.) A steeper slope leads to a gentler transition in temperature and can promote a slower and more regulated solidification process. Conversely, a steeper slope leads to a more distinct difference in temperature and the potential for faster solidification. Researchers can customise the microstructure and mechanical features of AMCs for specific applications by systematically changing the length of the cooling slope and evaluating its impact. (Sunil Kumar et al., 2019)

This work aims to elucidate the complex correlation between fly ash concentration, microstructure, and mechanical performance in AMCs through a thorough investigation of these interrelated characteristics. Researchers can obtain dependable and statistically significant data by maintaining consistent casting circumstances and doing repeated experiments for each set of parameters. This approach facilitates notable progress in the field. To fully harness the potential of fly ash-reinforced composites and its role in sustainable material solutions, it is crucial to examine the experimental results from the perspective of microstructure and mechanical properties. (Tanvar et al., 2018)

2.5 T6 HEAT TREATMENT

The T6 treatment is a popular method for boosting the mechanical properties of aluminium alloys.(Yang et al., 2024) This three-step process involves heating, rapid cooling, and a low-temperature heating stage. In the first stage, called solutionizing, the alloy is heated to dissolve certain components and secondary structures, forming a uniform mixture around 525°C for about 8 hours. This is followed by rapid quenching, typically in warm water for 2-3 minutes, to trap these elements in a highly concentrated state within the aluminium.

The third and final stage, known as artificial aging, involves reheating the alloy at a lower temperature (around 155°C for 4 hours). During this stage, the previously dissolved elements come out of solution and form tiny, evenly dispersed particles throughout the material. These particles significantly strengthen the material by hindering the movement of internal defects. This process not only improves hardness and tensile strength but also promotes a more stable internal structure.(Tiwari et al., 2017)

The T6 process significantly alters the internal structure and properties of aluminium alloys. The initial stage creates a uniform structure by dissolving existing features, and the rapid cooling preserves the elements in a concentrated state for subsequent strengthening. Finally, the aging process introduces particles that impede movement within the material, leading to increased strength and hardness. Notably, this treatment can also improve ductility by reducing residual stresses. This balance of strength and ductility makes T6-treated alloys valuable for demanding applications.(Safian et al., n.d.)

For aluminium matrix composites (AMCs) reinforced with fly ash, the T6 treatment can further enhance their performance. The fly ash particles themselves contribute to strength, and the heat treatment process optimizes this effect. During solutionizing, the aluminium matrix becomes more uniform, and quenching ensures even distribution of the fly ash particles. The aging stage then leads to the formation of fine precipitates around these particles, further boosting overall strength and hardness.(Al-Shmaisani et al., 2022)

Studies have shown that T6-treated AMCs exhibit superior tensile strength and hardness compared to untreated ones.(Yang et al., 2024) Specific parameters like solutionizing at 525°C for 8 hours, quenching in warm water for 2-3 minutes, and aging at 155°C for 4 hours are found to be optimal for achieving the best mechanical properties.(Yang et al., 2024) These conditions ensure the formation of small, well-distributed precipitates for the most effective strength enhancement. Additionally, the reduced residual stresses during aging can improve the composite's ductility, making it suitable for applications requiring both strength and formability, such as those found in the automotive and aerospace industries.

In conclusion, the T6 thermal treatment, with its precise steps of solutionizing, quenching, and artificial aging, significantly improves the mechanical properties of fly ash-reinforced aluminium composites. By optimizing the internal structure and dispersing tiny strengthening particles, this method effectively enhances both strength and hardness while potentially improving ductility. These enhancements make T6-treated AMCs highly desirable for advanced engineering applications demanding exceptional performance and durability.(Yang et al., 2024)

2.6 DESIGN OF EXPERIMENT (DoE)

The study on the effect of fly ash on aluminium matrix composites (AMCs) produced using cooling slope casting is crucial without mentioning the design of experiments (DoE) approach. DoE provides a systematic framework for examining the intricate interaction among several elements, allowing researchers to deliberately choose specific amounts for each parameter, such as fly ash concentration, pouring temperature, and cooling slope length. This approach reduces the need for numerous trials, optimizes data collection efforts, and gathers statistically significant data. (D. K. Yadav & Chakrabarty, 2020)

The study relies heavily on DoE to analyse the impact of fly ash content, pouring temperature, and cooling slope length on the microstructure and mechanical properties of AMCs. This understanding allows researchers to determine the most favourable processing conditions to achieve desired qualities, enhance the efficiency of the composite material, and reveal potential connections and complex linkages.

The use of DoE in this investigation of fly ash composites is essential for researchers to navigate the complex network of variables, gain significant insights, and facilitate the production of high-performance, sustainable materials by intelligently manipulating processing parameters.

2.6.1 RESPONSE SURFACE METHODOLOGY

While conducting research on the impact of fly ash content on aluminium matrix composites (AMCs) produced through cooling slope casting, response surface methodology (RSM) emerges as a powerful instrument to assist in this investigation. This advanced statistical technique functions as a mapmaker, providing clarity to the complex characteristics of your selected factors and uncovering the most favourable conditions for attaining desirable qualities in the AMCs.

Visualise a topographical representation wherein the highest points symbolise exceptional mechanical strength, resistance to wear, or other vital attributes. RSM enables you to effectively navigate this intricate landscape by developing mathematical models using experimental data. These models serve as comprehensive guides, precisely delineating the correlations between the selected variables - fly ash concentration, pouring temperature, and cooling slope length in specific scenario - and the ultimate characteristics of the AMCs. (Cheng et al., 2023)(Arjunraj et al., 2023)

The beauty of RSM rests in its capacity to measure the impacts of individual parameters and their interconnections. RSM extends beyond the mere indication that a higher fly ash content may enhance strength. It converts this subjective observation into a precise mathematical equation, establishing the precise numerical correlation between the increase in fly ash content and the resulting increase in strength. (Xiong et al., 2019) This quantitative comprehension sets the stage for exact optimisation tactics.

Through the analysis of built mathematical models, researchers are able to precisely identify the specific combination of parameters that produces the most favourable characteristics in the AMCs. (da Motta et al., 2023) This obviates the necessity for laborious and resource-intensive trial-and-error experimentation, hence greatly simplifying the optimisation process. RSM provides a distinct capability to generate visual depictions of the response surfaces. These graphic aids facilitate the comprehension of intricate connections between variables and their influence on performance. This inherent comprehension can catalyse subsequent investigation and innovation, promoting progress in the field of material design and production.

Within the context of this study, Response Surface Methodology (RSM) possesses significant capacity for enhancing the mechanical efficiency of AMCs. RSM can provide guidance in determining the optimal combination of fly ash content, pouring temperature, and cooling slope length that maximises the strength, wear resistance, or other important qualities. (Salleh et al., n.d.) This focused strategy guarantees the creation of high-performance composites customised to meet individual demands. Response surface methodology (RSM) can be employed to determine optimal parameter combinations that minimise porosity, shrinkage, or other potential disadvantages. This measure ensures the overall excellence and effectiveness of your composites, guaranteeing successful application in real-world scenarios. The mathematical models produced by RSM can be utilised to forecast the characteristics of upcoming AMCs manufactured with various parameter configurations. (Arjunraj et al., 2023) This predictive skill has the potential to decrease the necessity for significant experimentation, hence conserving time, and resources in the long term.

To summarise, RSM serves as a potent instrument in your investigation of fly ash composites. The capacity to measure, depict, and enhance the connections between variables enables you to explore the complex field of material attributes and discover the most effective processing conditions for producing high-performance, environmentally friendly AMCs. Ensure that you enhance the personalisation of this by including precise information on the selected RSM software or algorithms you intend to utilise, or by stating specific optimisation objectives you aim to accomplish with this technique. I trust that this information proves beneficial. Kindly inform me if you have any other inquiries.

2.6.2 TAGUCHI METHOD

The Taguchi Method, a robust optimisation technique developed by Genichi Taguchi, has great potential to improve the accuracy and efficiency of the study on the "Effect of Fly Ash Content on the Microstructure and Mechanical Properties of Aluminium Matrix Composites Processed by Cooling Slope Casting." This experimental design methodology provides a methodical strategy to simultaneously analyse several parameters, making it especially suitable for complex research that involve numerous variables.

Within the scope of the present study, the Taguchi Method facilitates the identification and optimisation of crucial parameters that have an impact on the microstructure and mechanical properties of aluminium matrix composites. Researchers can effectively assess the influence of several elements, such as fly ash levels, on desired outcomes by utilising orthogonal arrays and signal-to-noise ratios. (kumar et al., 2014) This methodology enables the examination of relationships between many factors, allowing for a comprehensive comprehension of the interconnection between fly ash content, cooling slope casting, and resulting material qualities. (kumar et al., 2014)

An important benefit of the Taguchi Method is its capacity to reduce experimental variability and improve the study's resilience. By employing a structured approach to conducting experiments, this strategy enables researchers to acquire dependable and replicable outcomes, therefore minimising the impact of extraneous variables that could complicate the analysis. This enhances the level of confidence in the study's conclusions, hence strengthening the validity and applicability of the findings to real-life situations. (Salleh et al., n.d.)

In addition, the Taguchi Method enhances resource efficiency by necessitating fewer experimental runs in comparison to conventional one-factor-at-a-time procedures. (kumar et al., 2014) This is especially beneficial in research projects that have limited resources or time constraints. Engineers have the ability to enhance the experimental procedure, saving time and money, while still gaining thorough understanding of the impact of fly ash content on the microstructure and mechanical characteristics of aluminium matrix composites.

Overall, the utilisation of the Taguchi Method in this study offers a systematic and effective approach to experimental design and analysis. This methodology improves the reliability, efficiency, and resource utilisation of the study by thoroughly examining the many interactions among important variables. As a result, it contributes to a more comprehensive knowledge of the complex linkages inside the investigated system. (Al-Shmaisani et al., 2022)

2.7 MICROSTRUCTURAL CHARACTERIZATION

The Fly Ash–Aluminium Matrix Composites were analysed using a range of analytical techniques to provide a detailed understanding of their composition and structural properties. The examination employed cutting-edge instruments, such as X-ray Diffractometer (XRD), Scanning Electron Microscope (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and Optical Microscope.(Salleh et al., n.d.)

The analysis of the microstructure of the Fly Ash–Aluminium Matrix Composites utilised a comprehensive methodology, which included the use of XRD to gain crystallographic information, SEM to examine surface morphology in detail, FTIR to analyse chemical composition, and Optical Microscopy to make macroscopic observations. By employing modern analytical approaches, a deep comprehension of the microstructural characteristics was achieved, facilitating a detailed assessment of the attributes of the composites.

2.7.1 X-RAY DIFFRACTION (XRD) ANALYSIS

X-ray Diffraction (XRD) analysis was crucial in conducting the microstructural examination. This method enables the determination of crystallographic information by measuring the diffraction pattern of X-rays that are directed onto the sample. The XRD study yielded significant information regarding the phase composition and crystal structure of the Fly Ash–Aluminium Matrix Composites, enabling a comprehensive comprehension of the material's internal organisation.

2.7.2 FRACTURE MORPHOLOGY OBSERVATION BY SCANNING ELECTRON MICROSCOPY (SEM)

The microstructural analysis was conducted using a Scanning Electron Microscope (SEM). Scanning Electron Microscopy (SEM) is an advanced imaging method that allows for the detailed examination of surface features and microstructure at a very small scale. The scanning electron microscopy (SEM) examination provided precise visual data regarding the dispersion of fly ash particles inside the aluminium matrix, revealing insights into the uniformity and interfacial properties of the composite material. (Ade Saputra et al., 2022)

Based on a study (Bharambe et al., 2023) (R. Yadav et al., 2023b) The use of the Scanning Electron Microscope (SEM) allowed for the qualitative verification of the elements contained in both the matrix and reinforcement, as depicted in the figure below.

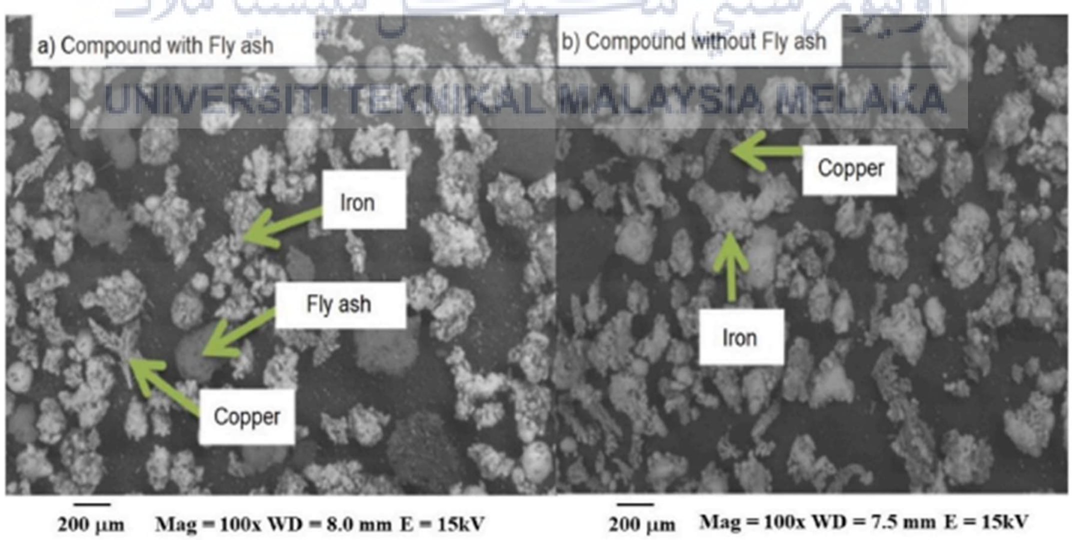

Figure 2-2 Matrix and chemical distribution of composites - sintered sample: a) Compound A with Fly Ash b) Compound without fly ash (da Motta et al., 2023)

2.7.3 OPTICAL MICROSCOPIC ANALYSIS

Optical microscopy was a crucial part of the procedure for characterising the microstructure. This method entails utilising visible light to visually examine and analyse samples on a large scale. Optical microscope analysis enabled the study of macroscopic characteristics, such as the general shape and arrangement of components. This method enhanced the high-resolution data obtained by SEM and offered a thorough comprehension of the structural properties of the material at various length scales.

2.8 MECHANICAL TESTING AND PROPERTIES

The pursuit of enhancing the effectiveness of aluminium matrix composites (AMCs) has a substantial chronicle in the realm of study, with fly ash appearing as a propitious contender for reinforcing. In order to fully comprehend the extent of its capabilities, it is necessary to explore the complex interplay of processes, mechanical tests, and microstructure, which ultimately governs the performance of these materials. (Vinoth Babu et al., 2022b) Through comprehending the mechanisms that amplify strength, conducting rigorous tests that expose performance, and observing the intricate interactions that govern behaviour, we gain access to the mysteries of fly ash-reinforced AMCs. This paves the path for the creation of advanced materials with unparalleled qualities in the future.

2.8.1 STRENGTHENING MECHANISMS AND MECHANICAL PROPERTIES

The literature functions as a navigational tool, directing us through the diverse methodologies utilised to enhance the robustness of AMCs. Particle reinforcement is highly effective, and fly ash is crucial in improving tensile strength, yield strength, and toughness. Theoretical frameworks and actual tests provide insights into the impact of different concentrations of fly ash on several mechanisms that enhance the strength of the composite material. (Vinoth Babu et al., 2022b)

2.8.2 MECHANICAL TEST

Assessing the actual value of an AMC relies on a thorough series of mechanical testing. Tensile tests, compression tests, and flexural tests serve as our means of inquiry, obtaining vital data regarding the material's ultimate tensile strength, compressive strength, and flexural strength, correspondingly. The literature review thoroughly analyses known methodologies for completing these tests, ensuring their appropriateness for AMCs manufactured using cooling slope casting. (Li et al., 2023) Furthermore, it examines the complex relationship between the amount of fly ash present and the results of these tests, uncovering the close link between composition and mechanical effectiveness.

2.8.3 HARDNESS TEST

Hardness testing, commonly utilising Vickers or Rockwell techniques emerges as a prominent approach to evaluate the material's ability to resist deformation. The literature study highlights the significance of these assessments, especially for Asset Management Companies (AMCs). This work rigorously examines the influence of varied levels of fly ash on the hardness of the composites, shedding light on their capacity to endure localised plastic deformation under diverse loading situations. (Alhawari et al., 2013)(Tiwari et al., 2017) This information enhances our comprehension of the mechanical properties of the material in various situations.

2.8.4 MICROSTRUCTURE INVESTIGATIONS

Gaining a comprehensive understanding of the structure of an AMC, including its complex arrangement of phases and elements, is of utmost importance. Scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray diffraction (XRD) serve as investigative instruments, allowing us to uncover the hidden details of the microstructure. The review examines the significant influence of microstructural characteristics, including particle dispersion, interfacial bonding, and grain structure, on the mechanical properties of AMCs. This work significantly explores the impact of fly ash content on the development of the microstructure, establishing a crucial connection between the composition, processing methods, and the resulting microstructural characteristics. (Li et al., 2023)

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

The study explores the impact of fly ash content on aluminium matrix composites (AMCs) fabricated via cooling slope casting. The material preparation involves commercially pure A356 aluminium alloy, which is compatible with fly ash. Different weight percentages of fly ash are used to create composite samples with varying reinforcement levels. A custom-designed cooling slope setup is used to fabricate AMC specimens, with three different cooling slope lengths employed to investigate their impact on solidification rate and heat extraction dynamics. Microstructure analysis using scanning electron microscopy (SEM) and X-ray diffraction (XRD) provides insights into the interfacial bonding and potential porosity of fly ash particles within the aluminium matrix. Mechanical testing measures the ultimate tensile strength, compressive strength, and Young's modulus of the composites. Vickers hardness measurements assess the resistance of the AMCs to localized plastic deformation. Statistical analysis is performed to identify correlations between fly ash content, casting parameters, microstructure features, and mechanical performance. (Praharaj et al., 2014)

3.2 GANTT CHART

The Gantt chart serves as a comprehensive visual representation of the project plan for Final Year Project 1, encompassing Chapters 1 to 3 as outlined in figure below and further detailed in the appendices. It provides a structured timeline for each activity, milestone, and resource allocation, facilitating efficient project execution and monitoring. By clearly illustrating the sequence of tasks and their interdependencies, the Gantt chart enhances communication and ultimately contributing to the successful completion of the project within established timeframes and resource constraints.

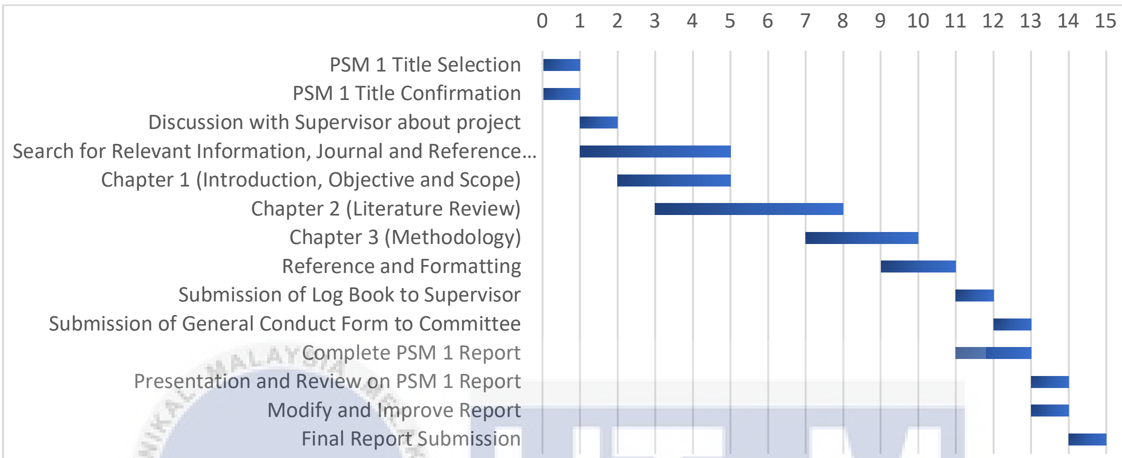

Figure 3-1 Gantt Chart for FYP 1

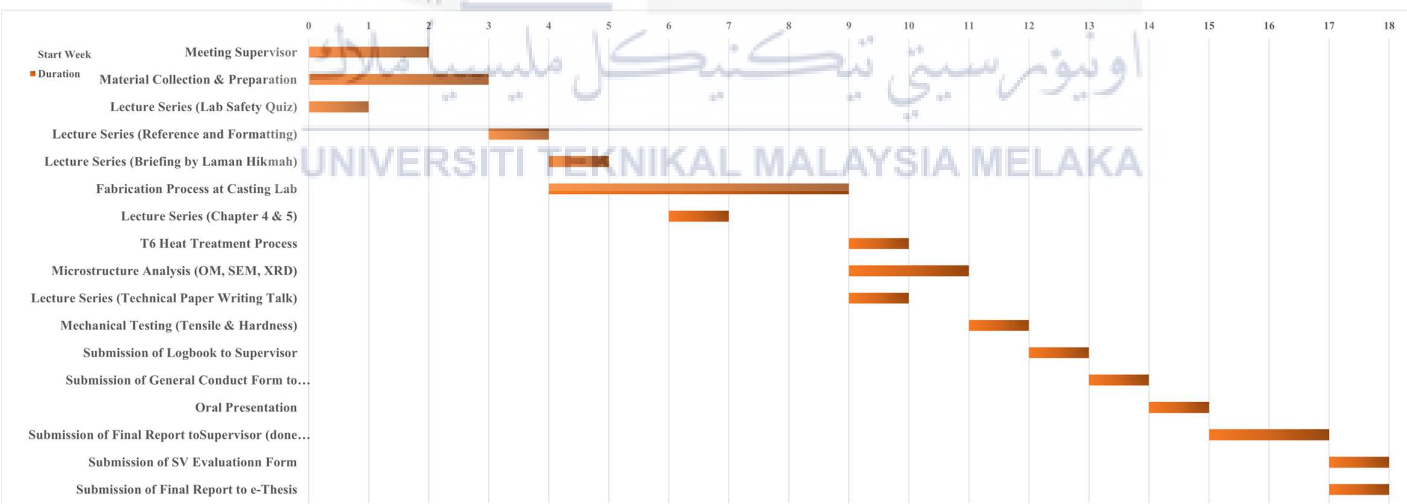

Figure 3-2 Gantt Chart for FYP 2

3.3 FLOW CHART OF OVERALL RESEARCH

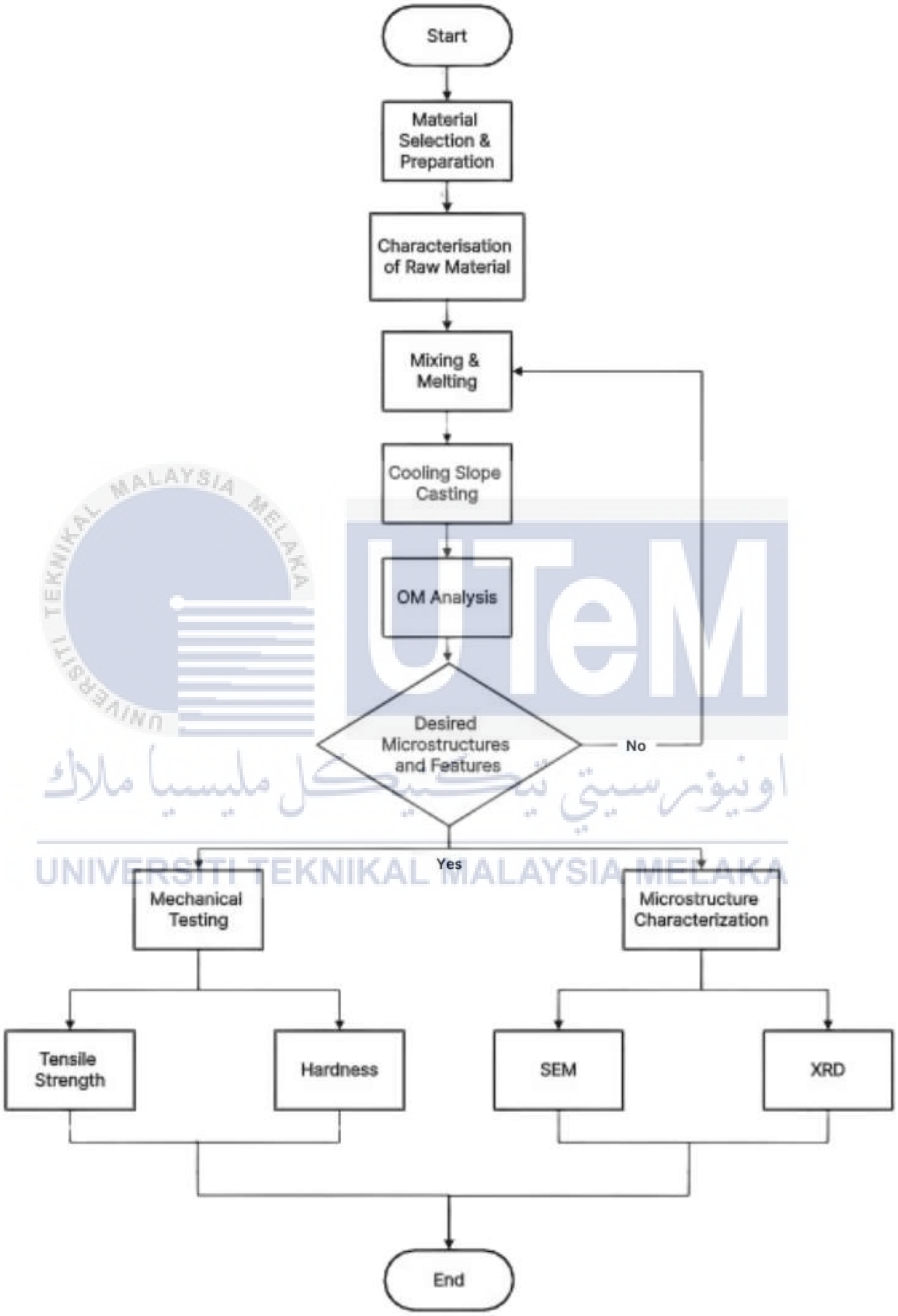

Figure 3-3 Flowchart of Overall Research

3.4 RAW MATERIALS

A356 alloy was used as the metal matrix and will be reinforced with fly ash to produce the aluminium matrix composite. (ASTM, 2020) (R. Yadav et al., 2023b) Both of these materials will be obtained from a power plant in Klang called YTL Power Plant. The chemical configuration for the alloy and fly ash are shown at Table 3.4-1 and Table 3.4-2.

Composition	Percentage
Si	7.25
Mg	0.45
Fe	0.086
Cu	0.010
Mn	0.018
Ni	0.025
Zn	0.005
others	0.028
Al	92.12

Table 3-1 Chemical Configuration of A356 alloy (Sunil Kumar et al., 2019)

Al2O3	SiO2	Fe2O3	TiO2	Carbon/LOI
29.9 %	56.92 %	8.44 %	2.75 %	1.99 %

Table 3-2 Composition of fly ash (wt%) (Arifin et al., 2018)

3.5 DESIGN OF EXPERIMENT (DoE)

The Design of Experiment (DoE) refers to the systematic plan for doing a project with the aim of describing and explaining the range of data under settings that are intended to simulate the variability. The phrase is primarily associated with experiments in which the design introduces variables that directly impact the variable, but it may also refer to the design of quasi-experiments, where natural conditions that influence the variable are selected for observation. At its simplest form, an examination aims to predict the outcome by introducing a variation in the conditions, which is represented by one or more independent elements, also referred to as "input factors" or "indicator factors." The modification of at least one independent variable is generally hypothesised to result in a modification of at least one dependent variable, also referred to as "output factors" or "response factors."

3.5.1 TAGUCHI METHOD

DOE comes in a variety of forms, including the Taguchi Method, Respond Surface Method, and Full Factorial. The Taguchi method will be utilised in this project due to the presence of three parameters: fly ash content, cooling slope length, and pouring temperature. These three parameters have distinct values, each corresponding to three levels for each variable. By designing experiments with different fly ash content levels and considering noise factors, Taguchi helps identify the optimal fly ash content that minimizes the influence of uncontrollable factors on the final mechanical properties

3.6 EXPERIMENTAL PROCEDURE

3.6.1 COOLING SLOPE CASTING PARAMETERS

The cooling inclined plate, made of stainless steel, has a width of 90mm and a tilt angle of 60°. The slope lengths are indicated at 200mm, 300mm, and 400mm. In the cooling slope casting experiment, the A356 alloy was heated to a temperature above 700°C in the furnace. For this experiment, the selected temperatures were 630°C, 640°C, and 650°C. (Safian et al., n.d.) The overheated alloy was subsequently cooled to its intended pouring temperature and then poured into a vertical stainless-steel mould with a diameter of 25 mm and a height of 120 mm, following a downward slope. The temperature of the molten substance was determined using a type-K thermocouple. The experiment was replicated using varying pouring temperatures and slope lengths. The cooling slope's surface was treated with a layer of boron nitride to prevent the melted alloy from sticking to the plate. For the conventional casting sample, the molten alloy was directly poured into the preheated mould at a temperature of 120°C.

Table 3-3 Parameter for this study

Experiment No.	Pouring Temperature (°C.)	Cooling Slope Length (mm)	Fly Ash Content (wt%)
1	630	200	0
2	630	200	4
3	630	200	8
4	630	200	12
5	640	300	0
6	640	300	4
7	640	300	8
8	640	300	12
9	650	400	0
10	650	400	4
11	650	400	8
12	650	400	12

3.6.2 FABRICATION PROCESS OF FLY ASH – AMCs

The selected matrix, aluminium alloy, is meticulously melted at a temperature of 800°C. The fly ash is carefully added to the molten metal in exact weight proportions of 4%, 8%, and 12%. (Xiong et al., 2019) To get a consistent mixture, we use a fast stirrer that stirs the blend for 5 minutes at a speed of 350 revolutions per minute. Subsequently, the liquefied mixture is carefully placed into a mould, prepared to undergo the cooling slope casting.

3.6.3 T6 HEAT TREATMENT

A multi-step thermal process, known as T6 treatment, is employed to optimize the mechanical performance of aluminium alloys and their composites. This treatment involves three distinct stages with specific parameters for each. The first stage, solutionizing, involves heating the material to a high temperature (around 525°C for 8 hours) to dissolve specific components and secondary structures. This creates a uniform mixture within the material. Quenching, which is a rapid cooling process, achieved through soaking the AMC in water (typically for 2-3 minutes), follows to trap these elements in a highly concentrated state.

The final stage, artificial aging, involves reheating the material at a lower temperature (around 155°C for 4 hours). During this stage, the previously dissolved elements come out of solution and form tiny, evenly dispersed particles throughout the material. The presence of these particles greatly augments the strength of the material by impeding the mobility of internal flaws.(Tiwari et al., 2017) This procedure enhances both the hardness and tensile strength of the material and has the potential to increase its ductility by minimising residual stresses. It is essential to optimise the settings of the T6 treatment in order to achieve optimal outcomes.

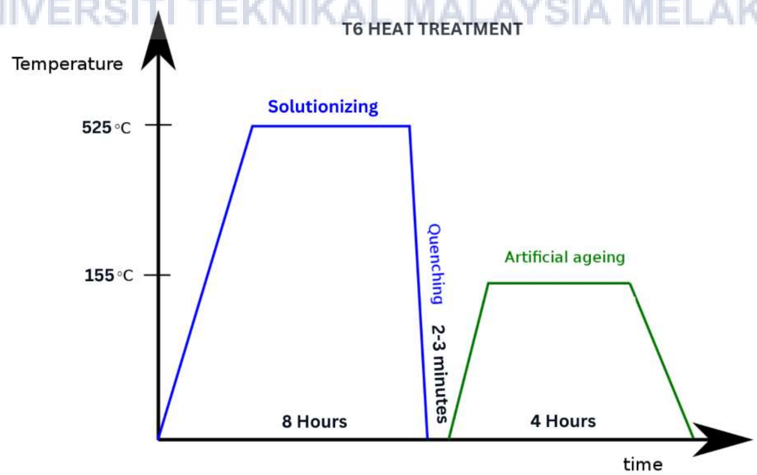

Figure 3-4 Graphical Representation of T6 Heat Treatment

Research suggests that specific settings, such as solutionizing at 525°C for 8 hours, quenching in warm water for 2-3 minutes, and aging at 155°C for 4 hours, lead to the formation of small, well-distributed strengthening particles.(Yang et al., 2024) This configuration maximizes the improvement in strength and hardness. These parameters are particularly important for aluminium matrix composites reinforced with fly ash particles, where the T6 treatment further enhances the strength achieved by the fly ash itself.

3.7 MICROSTRUCTURE CHARACTERISATION OF FLYA SH – ALUMINIUM MATRIX COMPOSITE

3.7.1 X-RAY DIFFRACTION (XRD)

X-ray diffraction (XRD) played a vital role in our study on the impact of fly ash content on aluminium matrix composites (AMCs) produced using cooling slope casting. It was important in revealing the hidden crystalline information present in the samples. This technique enabled us to investigate the fundamental atomic arrangement, yielding important understanding of the existing phases, their interactions, and ultimately, the impact of fly ash on the microstructure and mechanical properties of the composites.

A highly concentrated X-ray beam, similar to a tiny spotlight, is aimed at the sample. The interaction between X-rays and atoms in a material causes the electrons of the atoms to move and scatter the incoming X-ray beam. The diffracted X-rays subsequently propagate, conveying precise details regarding their interactions with the atomic lattice. Through the examination of the intensity and angles of these diffracted beams, we are able to recreate the fundamental crystal structure of the material. This enabled us to precisely determine the presence of aluminium, fly ash minerals, and any resulting reaction products that were generated during the processing of the AMCs. (He et al., 2024)

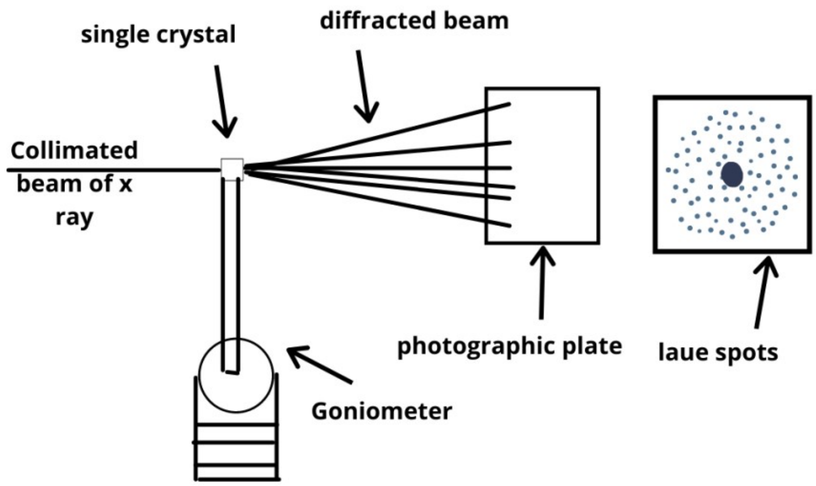

Figure 3-5 Principle of XRD Analysis (He et al., 2024)

Through meticulous examination of the relative intensities of the diffracted peaks, we can ascertain the proportional quantities of each phase, thereby unveiling the impact of fly ash content on the crystallographic composition of the composites. XRD can provide insights into the interactions between different phases, perhaps revealing the development of bonds at interfaces or alterations in crystal structure caused by the presence of fly ash. (He et al., 2024)(Alhawari et al., 2013)

By integrating this information with data obtained from further characterisation techniques, such as scanning electron microscopy (SEM), we can construct a full depiction of the microstructure and its correlation with the mechanical properties of the fly ash-reinforced AMCs. By comprehending this knowledge, we get the ability to fine-tune the processing settings and fly ash content in order to produce high-performance materials that possess customised qualities suitable for various applications.

3.7.2 FRACTURE MORPHOLOGY OBSERVATIONS BY SCANNING ELECTRON MICROSCOPY (SEM)

Scanning electron microscopy (SEM) proved to be an invaluable tool in our investigation of the complex relationship between fly ash content and the microstructure of aluminium matrix composites (AMCs) produced through cooling slope casting. By employing this advanced method, we were able to observe the structure of the composite material at a very small level, which gave us important information on how the fly ash particles are distributed, how they interact with the aluminium matrix, and the general characteristics of the material that determine its mechanical properties.

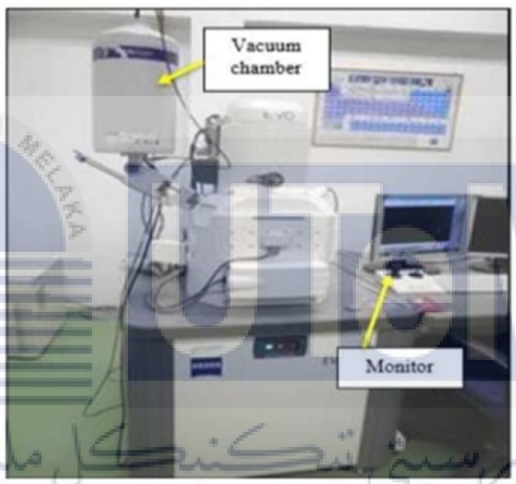

Figure 3-6 Zeiss EVO-50 SEM machine

AMC samples were meticulously processed to ensure the highest possible image quality and conductivity. Surfaces were delicately purged with air pressure to eliminate any particles that could obstruct the microstructure. Next, the samples were carefully attached to aluminium stubs to ensure they remained in a stable position inside the SEM chamber. Our access to the microstructural realm was facilitated by the utilisation of a Zeiss EVO-50 Scanning Electron Microscope (SEM) apparatus, as depicted in Figure 3.7-2 The samples were carefully placed within the SEM chamber and exposed to a concentrated stream of electrons. - The secondary electrons emitted from the surface of the sample were carefully gathered to create high-resolution images that revealed small-scale structural features. In order to have a thorough comprehension of the microstructure, we analysed the samples at various levels of magnification.

This information provides insight into the effectiveness of reinforcement and the possibility of clustering effects that may impact mechanical behaviour. Robust interfacial adhesion between fly ash particles and the aluminium matrix is crucial for efficient load transmission and overall composite durability. Scanning Electron Microscopy (SEM) detects the existence of porosity, grain boundaries, and other microstructural features that can have a substantial influence on mechanical properties.

The knowledge obtained from scanning electron microscopy (SEM) analysis, when integrated with data from X-ray diffraction (XRD) and mechanical testing, offers a comprehensive comprehension of the connections between fly ash composition, microstructure, and the effectiveness of advanced composite materials (AMCs). This expertise enables us to fine-tune processing settings and reinforcement procedures, facilitating the creation of high-performance composites with customised qualities for various purposes.

3.8 MECHANICAL TESTING

3.8.1 TENSILE TESTING

The tensile specimens were prepared following the deliberating concept of the American Society for Testing of Materials (ASTM E8M-04) can refer figure 3-5 and table 3-4. (ASTM, 2020) Subsequently, the tensile tests were performed according to the design matrix using a 100 KN Electromechanical controlled universal testing machine. Machine for conducting tests. The tensile specimens were prepared for both the parent metal and the fabricated CNT reinforced magnesium composites. In order to achieve a consistent distribution of the reinforcement within the matrix, the microstructures are examined by experimental analysis utilising an optical metallurgical microscope.

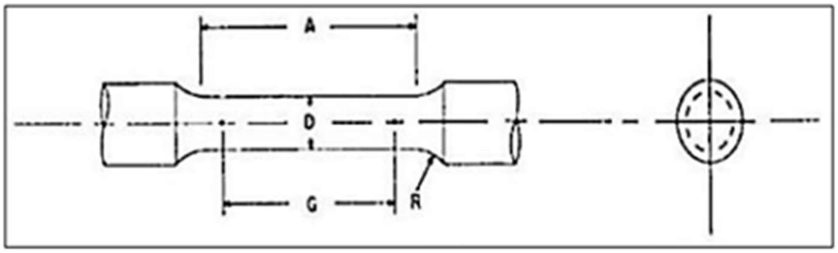

Figure 3-7 Graphical representation of ASTM E8M (04)

Table 3-4 Small-Size Specimen Proportional to Standard

ASTM E8M	09	06	04	25
G – Gage length	45.0 ± 0.1	30.0 ± 0.1	20.0 ± 0.1	12.5 ± 0.1
D – Diameter (Note 1)	9.0 ± 0.1	6.0 ± 0.1	4.0 ± 0.1	2.5 ± 0.1
R – Radius Fillet, min	8	6	4	2
A – Length of reduced section, min (Note 2)	54	36	24	20

3.8.2 HARDNESS TESTING

The fabricated composites were precisely trimmed to the specified dimensions in accordance with ASTM standards in order to conduct various mechanical evaluations. (ASTM, 2020) The Vickers hardness test was used to assess the microhardness of fly ash reinforced aluminium matrix composite. The machine, a SHIMADZU HMV-T1 model from Japan, is an advanced technique used for evaluating hardness. The ASTM-E384-99E1 standard was used to establish the tiny hardness sample. The instances' hardness was assessed using a 0.5 kg load for a duration of 15 seconds, and the measurements were documented.

CHAPTER 4
RESULTS & DISCUSSIONS

4.1 INTRODUCTION

This chapter explores the effects of incorporating fly ash into aluminium matrix composites (AMCs) fabricated through cooling slope casting. By analysing the results from tensile testing, hardness testing, and microstructure examinations, we aim to understand how varying fly ash content influences the internal structure (microstructure) and mechanical performance of the composites. This analysis will discuss the observed relationships between fly ash content and properties like strength, hardness, and ductility, ultimately revealing the effectiveness of fly ash as a reinforcing agent in these AMCs produced using the cooling slope casting method.

4.2 INVESTIGATE THE PARAMETERS

4.2.1 TAGUCHI METHOD

Table 4-1 Parameter Setting

No. Run	Pouring Temperature (°C.)	Cooling Slope Length (mm)	Fly Ash Content (wt%)
1	630	200	4
2	630	300	8
3	630	400	12
4	640	200	8
5	640	300	12
6	640	400	4
7	650	200	12
8	650	300	4
9	650	400	8

Minitab utilizes orthogonal arrays for Taguchi designs. These arrays are structured to provide efficient experimentation with minimal runs. However, standard orthogonal arrays typically accommodate factors with the same number of levels. Therefore, the Taguchi method can only show 3 factors with 3 levels of design which are Pouring Temperature (630°C /640°C /650°C.), Cooling Slope Length (200 mm /300 mm /400 mm) and Fly Ash Content (4wt%, 8wt%, 12wt%). However, the data for 0wt% Fly Ash Content were still experimented for microstructures and mechanical properties.

Based on Table 4-1, the Minitab Taguchi method is utilized to create nine sample runs with varying parameters to analyse their effects on the material properties. These parameters include pouring temperature, cooling slope length, and fly ash content. The experiments are structured to ensure a comprehensive analysis by varying one parameter at a time across the different runs.

For the first set of runs, labelled as run 1 to 3, a pouring temperature of 630°C is used. Each of these runs incorporates a different cooling slope length of 200 mm, 300 mm, and 400 mm, respectively, combined with varying fly ash content of 4 wt%, 8 wt%, and 12 wt%. This systematic variation helps in understanding how different cooling slope lengths and fly ash content at this specific temperature influence the composite's properties.

The next set of experiments, run 4 to 6, is conducted at a higher pouring temperature of 640°C. Similar to the first set, these runs vary the cooling slope lengths (200 mm, 300 mm, and 400 mm) and fly ash content (4 wt%, 8 wt%, and 12 wt%). This allows for a comparison between the effects of the 630°C and 640°C pouring temperatures on the mechanical properties of the composites.

Finally, run 7 to 9 are performed at an even higher pouring temperature of 650°C, with the same variations in cooling slope length (200 mm, 300 mm, and 400 mm) and fly ash content (4 wt%, 8 wt%, and 12 wt%). By systematically altering the pouring temperature, cooling slope length, and fly ash content across these nine runs, the Taguchi method facilitates a thorough investigation into the optimal conditions for enhancing the mechanical properties of fly ash reinforced aluminium matrix composites

Table 4-2 Data collected from tensile testing

Experiment No.	Pouring Temperature (°C.)	Cooling Slope Length (mm)	Fly Ash Content (wt%)	Ultimate Tensile Strength (N/mm²)	Yield Strength (N/mm²)	Elongation (%)
1	630	200	0	218.59	217.347	2.1005
2	630	200	4	244.95	243.458	5.605
3	630	200	8	271.31	269.569	10.025
4	630	200	12	297.67	295.68	14.445
5	640	300	0	229.391	216.347	1.0890
6	640	300	4	256.816	238.3354	4.4158
7	640	300	8	284.241	277.526	10.3525
8	640	300	12	311.665	316.7166	16.2892
9	650	400	0	180.398	165.759	2.904
10	650	400	4	191.725	177.263	5.9841
11	650	400	8	259.124	251.664	8.89
12	650	400	12	326.523	326.065	16.8214

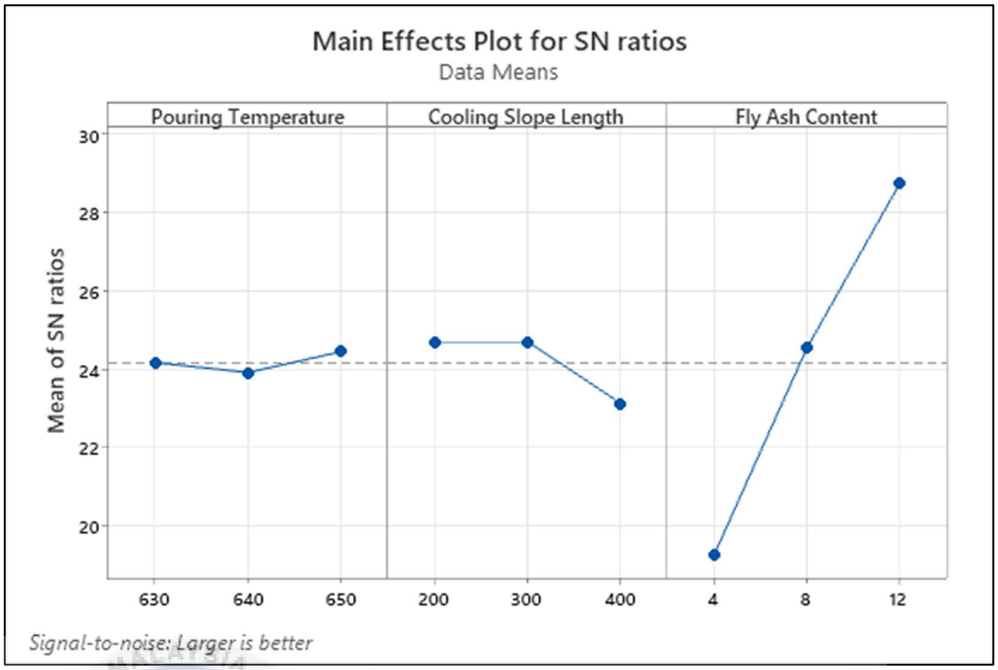

Figure 4-1 Main Effect Plot for SN ratios

Based on the data we collected (refer to Table 4-2 Data Collected from Tensile Testing), the data were analysed, and Figure 4-1 were created. The Taguchi method analyse the ultimate tensile strength, yield strength, and elongation versus the pouring temperature, cooling slope length and fly ash content. The primary effects figure for signal-to-noise (SN) ratios demonstrates the impact of several parameters on the SN ratio, where a greater SN ratio signifies superior performance. The criterion of "larger is better" is employed to evaluate the influence of every factor. (kumar et al., 2014)

The first factor is pouring temperature, which are at 630°C, 640°C, and 650°C. The graph shows that the average signal-to-noise ratio remains pretty consistent across different temperatures. Within this range, the pouring temperature has a little impact on the signal-to-noise ratio, indicating a high level of stability. Therefore, the fluctuations in pouring temperature have a small impact on the performance of the aluminium matrix composites.

Next, the length of the cooling slope is determined using measurements taken at distances of 200 mm, 300 mm, and 400 mm. The average signal-to-noise ratio exhibits a little rise from 200 mm to 300 mm, suggesting a small enhancement in performance with the middle cooling slope length. However, as the cooling slope length reaches 400 mm, the average signal-to-noise ratio falls, indicating that a longer cooling slope may negatively impact the signal quality relative to the background noise. Thus, although the length of the cooling slope does have an influence, its impact is limited, and longer lengths may have a detrimental effect on the material qualities.

The most notable differences are observed in the fly ash content, which was evaluated at 4 wt%, 8 wt%, and 12 wt%. The plot demonstrates a significant correlation between the increase in fly ash concentration and the rise in the mean SN ratio. The data shows a considerable increase in the signal-to-noise ratio when the fly ash content is increased from 4 wt% to 12 wt%. These findings indicate that a significant increase in the fly ash content greatly enhances the mechanical characteristics and overall performance of the aluminium matrix composites

To summarise, the primary effects plot indicates that the pouring temperature and cooling slope length have minimal to moderate influence on the SN ratio, however the fly ash content has a significant and favourable effect. Higher fly ash content results in a notable enhancement in the performance of aluminium matrix composites, as seen by the increased signal-to-noise ratios. However, based on the SN ratio, the optimal parameters are as in Table 4-3.

Table 4-3 Optimal Parameters Based on the SN ratio

Pouring Temperature	650°C
Cooling Slope Length	200mm
Fly Ash Content	12 wt%

4.3 EFFECT OF FLY ASH CONTENT ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AMCS PROCESSED BY COOLING SLOPE CASTING

The use of fly ash in aluminium matrix composites (AMCs) through cooling slope casting enhances their microstructure and mechanical properties. This low-cost, available reinforcing agent improves strength and hardness. This section explores how varying the fly ash content influences the microstructural characteristics and mechanical performance of AMCs produced using the cooling slope casting.

4.3.1 MICROSTRUCTURE ANALYSIS

Analysing the microstructure of a material at the microscopic scale is essential for comprehending its characteristics and behaviours. Optical microscopy, Scanning Electron Microscopy (SEM), and X-ray Diffraction (XRD) are highly effective technologies used for this purpose. These methods offer significant information about the dimensions and dispersion of internal units (grains), the boundaries between them, the different material components (phases), and the underlying arrangement of atoms (crystal structure). Moreover, they have the ability identify defects and unwanted elements that can have a significant impact on the material's performance. This study seeks to break down the effects of fly ash on the overall effectiveness of Aluminium Matrix Composites (AMCs).

4.3.1.1 MICROSTRUCTURE OF AMCs WITH AND WITHOUT FLY ASH

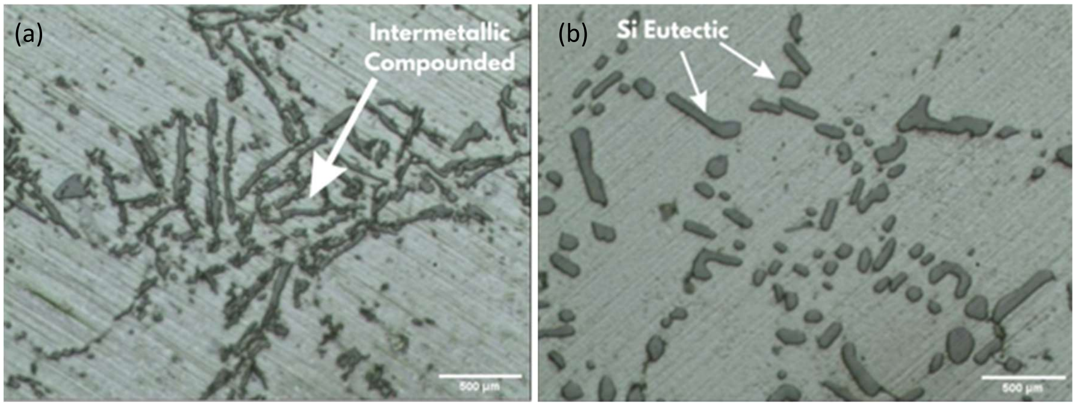

Figure 4-2 Optical microscopy images of (a) AMCs without fly ash and (b) AMCs with fly ash

Sample number 9 were chosen to represent the microstructure of AMCs without fly ash while sample number 12 were chosen to represent the microstructure of AMCs with fly ash as both the sample were processed in same parameter which are pouring temperature 650°C and cooling slope length of 400 mm. Besides both samples show the highest mechanical properties in term of ultimate tensile strength and yield strength in their respective fly ash content group. Therefore, both of these samples are a great choice to represent and show the microstructure analysis.

From Figure 4-2, (a) which is sample number 9 shows the absence of fly ash results in a microstructure that can be identified by larger, elongated dendritic grains. These grains are formed as a result of a slower solidification process, which allows dendrites to develop widely before encountering any obstacles. The increased size of these grains might have a negative effect on the mechanical properties of the composite, as it can result in weaker grain boundaries and reduced overall strength. (Wang et al., 2020)

The composite without fly ash displays larger primary aluminium grains and eutectic phases in relation to the primary and eutectic phases. The increased size of the grains during solidification is a direct result of the limited number of nucleation sites.(R. Yadav et al., 2023a) Increased grain size and presence of different phases can lead to decreased mechanical characteristics due to a less uniform microstructure and the presence of bigger areas of weakness.

The absence of fly ash in the composite results in a restricted number of nucleation sites during the solidification process. The limited number of nucleation sites leads to a reduced formation of grains, enabling the existing grains to grow larger and more broadly. (R. Yadav et al., 2023b)The decreased quantity of nucleation sites contributes to the formation of a larger microstructure, which might have a detrimental effect on the mechanical properties of the composite.

Conversely, the microstructure containing fly ash in Figure 4-1 (b) which is sample number 12 shows smaller, more spherical grains. Fly ash particles promote heterogeneous nucleation, leading to a more refined and evenly distributed grain size. The improvement in the grain structure often boosts the mechanical characteristics of the composite, such as its tensile strength and hardness, by creating a stronger and more uniform distribution of grains.(D. K. Yadav & Chakrabarty, 2020)

The fly ash particles contribute to the refinement effect of the composite, resulting in the primary and eutectic phases being finer. The greater quantity of nucleation sites offered by the fly ash prevents the development of bigger grains, resulting in a more evenly dispersed microstructure.(R. Yadav et al., 2023b) The uniform and balanced distribution of phases enhances the mechanical characteristics, resulting in increased durability and strength of the composite.

At last, fly ash particles greatly enhance the quantity of nucleation sites during the process of solidification as stated by (R. Yadav et al., 2023a) . This leads to a more uniform microstructure characterised by smaller, uniformly dispersed grains and phases. The presence of fly ash particles creates extra nucleation sites, resulting in a more refined microstructure. This refinement prevents the creation of massive dendritic grains and promotes a more homogeneous material, ultimately leading to improved mechanical characteristics.

4.3.1.2 BEFORE T6 HEAT TREATMENT

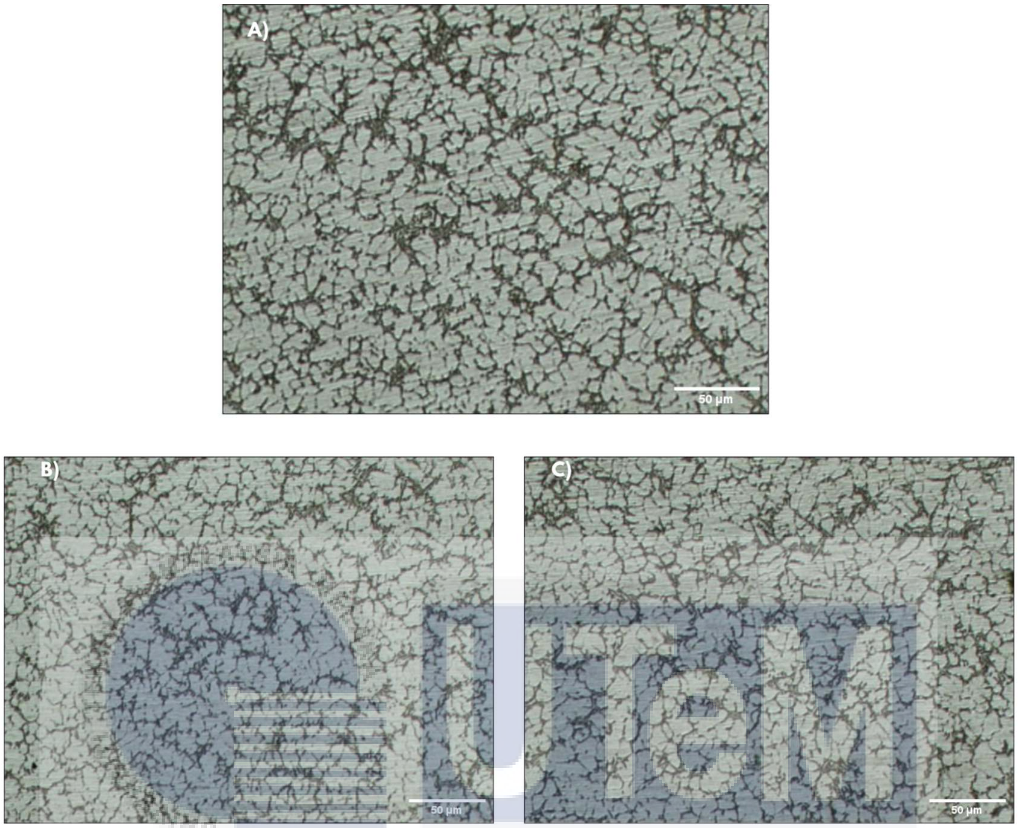

Figure 4-3 Optical microscopy images before T6 heat treatment (A) Sample number 10 (B) Sample number 11 (C) Sample number 12

Figure 4-3 shows the optical microscopy images which show the microstructures of three different samples before undergoing the T6 heat treatment process. Each sample has a varying fly ash content: (A) sample number 10 with 4% fly ash, (B) sample number 11 with 8% fly ash, and (C) sample number 12 with 12% fly ash. These samples were chosen to represent the microstructure analysis before T6 heat treatment because of in the optimal pouring temperature parameter which is 650°C. All of these samples were also fabricated with the same cooling slope length which is 400 mm as a constant variable factor.

The microstructure of sample number 10, containing 4% fly ash, shows a relatively coarse grain structure with noticeable primary aluminium dendrites. The distribution of fly ash particles is somewhat sparse, which leads to fewer nucleation sites and allows the dendritic structures to grow larger. This relatively coarser microstructure might result in lower mechanical properties compared to samples with higher fly ash content due to the larger grain sizes and less uniform distribution of reinforcing particles.

In sample number 11, which contains 8% fly ash, the microstructure becomes noticeably finer and more refined compared to sample A. The increase in fly ash content provides more nucleation sites during the solidification process, leading to a reduction in the size of the primary aluminium dendrites and a more homogeneous distribution of the phases. This finer microstructure indicates improved mechanical properties, as the smaller, more evenly distributed grains can enhance the composite's strength and hardness.

The microstructure of sample number 12, with 12% fly ash, shows a further refined and equiaxed grain structure. The high content of fly ash significantly increases the number of nucleation sites, leading to a very fine and uniform distribution of grains and phases throughout the composite. This structure is expected to exhibit superior mechanical properties due to the uniform and fine grain size, which enhances the strength, hardness, and overall durability of the material based on (R. Yadav et al., 2023b)

In summary, the addition of fly ash in the aluminium matrix composites processed by cooling slope casting results in a progressively finer and more homogenous microstructure as the fly ash content increases which also supported by (D. K. Yadav & Chakrabarty, 2020) The increased nucleation sites provided by the fly ash particles during solidification help in refining the grain structure, which is expected to improve the mechanical properties of the composites before the T6 heat treatment process.

4.3.1.3 AFTER T6 HEAT TREATMENT

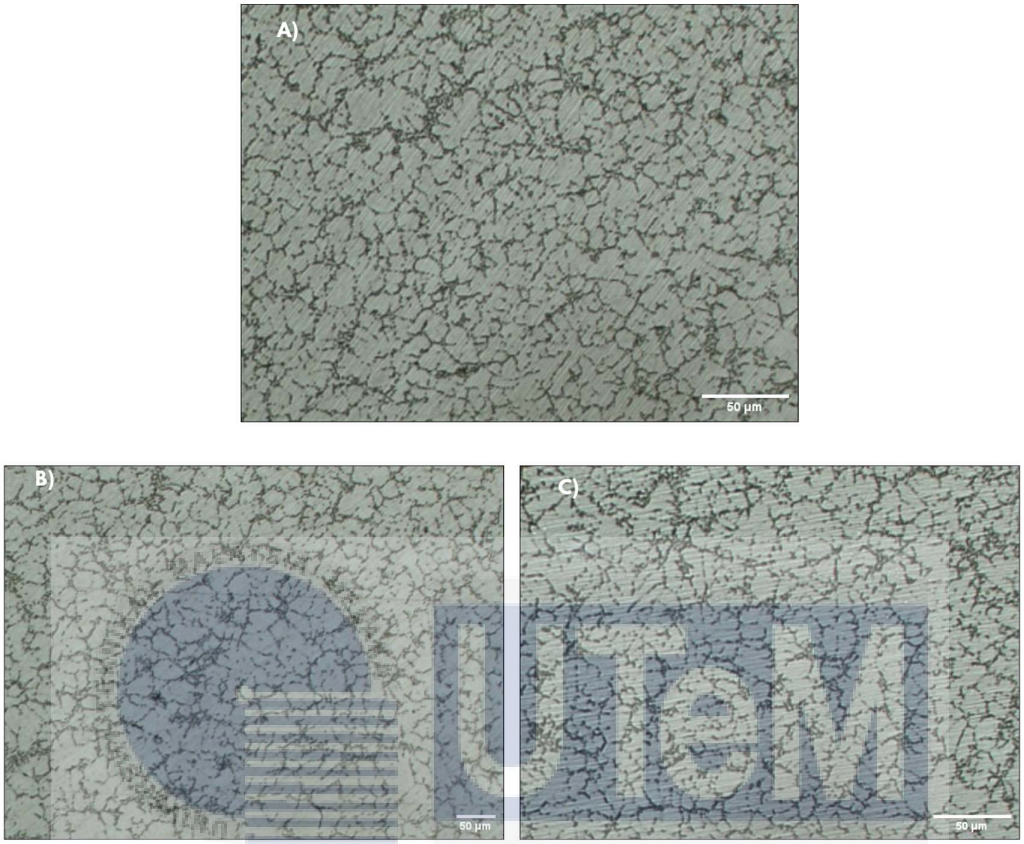

Figure 4-4 Optical microscopy images after T6 heat treatment (A) Sample number 10 (B) Sample number 11 (C) Sample number 12

Figure 4-4 represent the optical microscopy images show the microstructures of three distinct samples following the T6 heat treatment process. The fly ash content of each sample varies as follows: (A) sample number 10 contains 4% fly ash, (B) sample number 11 contains 8% fly ash, and (C) sample number 12 contains 12% fly ash. The parameters are the same as before the T6 heat treatment.

Sample A, which contains 4% fly ash, has a significantly refined microstructure after undergoing T6 heat treatment, as compared to its initial state before the heat treatment. The dendritic structures exhibit greater fragmentation, whereas the grains display a more balanced morphology and are evenly dispersed. The fly ash particles act as nucleation sites, facilitating the homogeneity of the microstructure. The anticipated outcome of this refinement is an improvement in the mechanical characteristics,(Yang et al., 2024) specifically the tensile strength and hardness, as a result of achieving a more consistent grain structure.

Sample B, which contains 8% fly ash, shows a microstructure after T6 heat treatment that has even smaller and more uniformly shaped grains compared to sample A. The increased fly ash content creates more locations for nucleation during the solidification process, which is further improved by the T6 heat treatment.(Tiwari et al., 2017) This leads to a substantial decrease in the size of the grains and a more uniform dispersion of the reinforcing particles. The enhanced microstructure is expected to result in higher mechanical qualities, such as heightened strength and hardness, as a result of the smaller grains.

Sample C, which contains 12% fly ash, has the most polished and homogeneous microstructure following the T6 heat treatment. The elevated fly ash concentration induces a greater quantity of nucleation sites, leading to the formation of a highly refined and uniformly distributed grain structure inside the composite material. The T6 treatment effectively disintegrates any remaining dendritic structures, resulting in a very purified and uniform microstructure. Due of the ideal microstructural refinement, this sample is anticipated to have exceptional mechanical properties, including superior tensile strength, hardness, and maybe enhanced ductility based on (Yang et al., 2024).

As a result, the inclusion of fly ash and the implementation of T6 heat treatment greatly enhance the microstructure of aluminium matrix composites produced using cooling slope casting. Increasing the amount of fly ash leads to a more consistent and smaller grain structure, which is additionally improved by the T6 treatment. The enhanced microstructure is anticipated to significantly enhance the mechanical characteristics of the composites, rendering them appropriate for high-performance applications.

4.3.1.4 FRACTURE MORPHOLOGY

Figure 4-5 shows the fracture morphology of fly ash reinforced aluminium matrix composites observed by scanning electron microscopy (SEM). The sample use to represent this analysis was sample number 12 with 12 wt% Fly Ash. All of the sample show some interesting features which helps in identifying the properties fly ash reinforced AMCs.

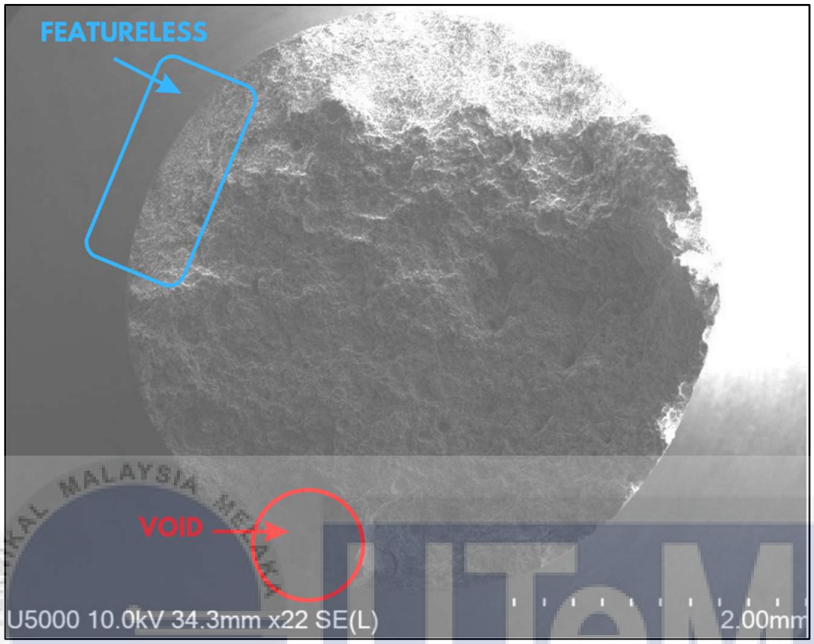

Figure 4-5 Image of fracture morphology of sample 12

Figure 4-5 indicates the existence of a brittle fracture in the relatively smooth and unremarkable region. Brittle fractures usually happen without extensive plastic deformation and are identified by a smooth surface. This fracture can be attributed to the existence of extremely small grain sizes that occur as a result of the refinement process of fly ash, or due to the presence of defects in the casting. The brittleness of the material can be attributed to its limited capacity for substantial plastic deformation prior to failure, typically leading to a rapid and catastrophic fracture.

On the other hand, the image also displays areas with a coarse and irregular texture, exhibiting attributes such as tears and empty spaces. This morphology is characteristic of ductile fracture. Ductile fractures are characterised by visible plastic deformation, and the rough surface is caused by the material experiencing substantial deformation prior to complete failure.(Vinoth Babu et al., 2022) The existence of empty spaces and creases indicates strong adhesion between the fly ash particles and the aluminium matrix, enabling a certain degree of malleability. The presence of ductile areas in the composite suggests that it is capable to absorb and release a larger quantity of force prior to breaking, in contrast to the brittle parts.

The picture from the scanning electron microscope (SEM) makes it very evident that there is a void present. Common features of composite materials, voids can be the site of initial and future cracking. Voids can significantly reduce the composite's mechanical properties, which reduces its overall toughness and strength. The effect of voids on composite material performance is mostly determined by their size and distribution.

Overall, a combination of brittle and ductile fracture characteristics is shown in the fracture morphology of the fly ash reinforced aluminium matrix composite according to the scanning electron microscope (SEM) examination. Small grain sizes or casting process flaws may be the cause of the little plastic deformation indicated by the existence of brittle fracture zones.(Xiong et al., 2019) However, ductile fracture zones show that the fly ash particles and the aluminium matrix are well bonded, allowing for some plastic deformation before failure. Maximising the mechanical performance and reliability of these composites in practical uses requires a thorough grasp of their fracture behaviours.

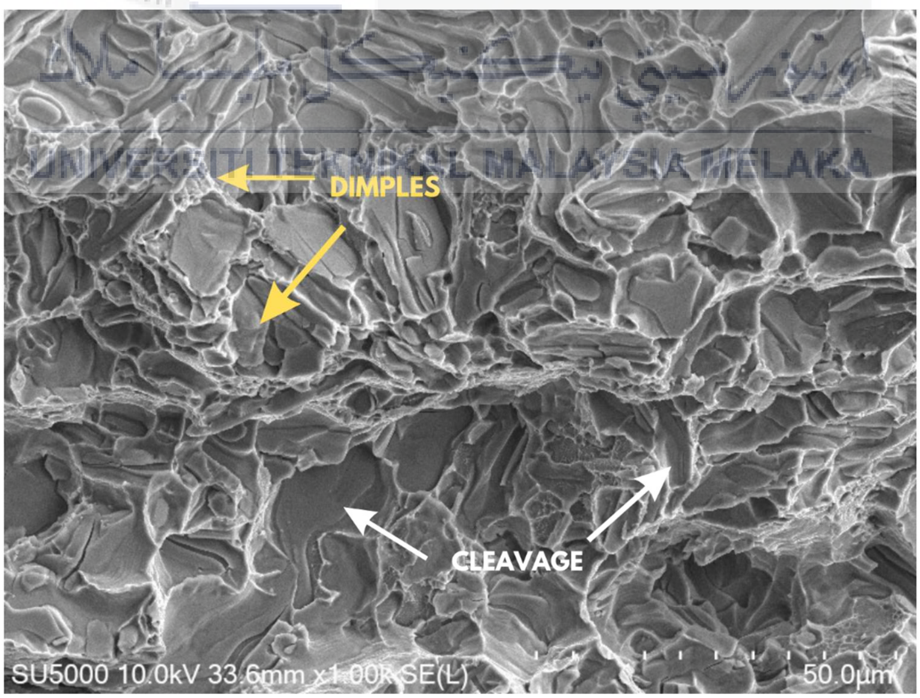

Figure 4-6 SEM image show the presence of dimples and cleavage

Based on figure 4-6, it reveals the presence of both cleavage and dimples in the fracture morphology of the fly ash reinforced AMCs which indicates it has different fracture behaviour. The flat, featureless regions on the fracture surface that show cleavage suggest little material strain or deformation during fracture. Usually, brittle fracture is connected to this feature. The fast spread of fractures along particular crystallographic planes with weaker atomic connections gives rise to cleavage surfaces. The existence of cleavage in the context of the fly ash reinforced AMCs indicates areas where the material broke without appreciable plastic deformation, perhaps because of the brittle nature of the reinforcement particles or inherent flaws produced during the composite manufacturing. (da Motta et al., 2023)

By comparison, the image also includes areas with dimples, which are little, circular depressions on the fracture surface. Dimples are a characteristic of ductile fracture, in which the material is significantly plastically deformed before to failure. The material's nucleation, development, and coalescence of microscopic voids as it is stretched produce the dimples. This suggests that before the composite finally failed, it showed some toughness and underwent plastic deformation. The composite may absorb and release energy by plastic deformation because of the strong connection between the fly ash particles and the aluminium matrix indicated by the dimples.

Fly ash reinforced AMCs' fracture surface SEM image shows both cleavage and dimples, indicating a mixed style of fracture behaviour. The places where the material failed fast and with little deformation are indicated by the cleavage-marked brittle zones. The brittle character of the fly ash particles or localised stress concentrations may affect these regions. Conversely, the dimpled portions exhibit toughness and the ability of the material to absorb energy before failing by indicating places where it could deform plasticly. Given the intricate interaction between the reinforcing particles and the aluminium matrix, this mixed fracture behaviour is noteworthy since it emphasises the composite's ability to display both brittle and ductile properties based on the local stress and microstructural circumstances as concluded by (da Motta et al., 2023)

Fly ash reinforced AMCs can display both brittle and ductile fracture behaviours, as seen by the combination of cleavage and dimples seen in the SEM image analysis of the fracture morphology. Ensuring that the composite may be successfully used in applications requiring a balance of strength and toughness depends on an understanding of these characteristics.

4.3.1.5 ENERGY DISPERSIVE X-RAY (EDX) ANALYSIS

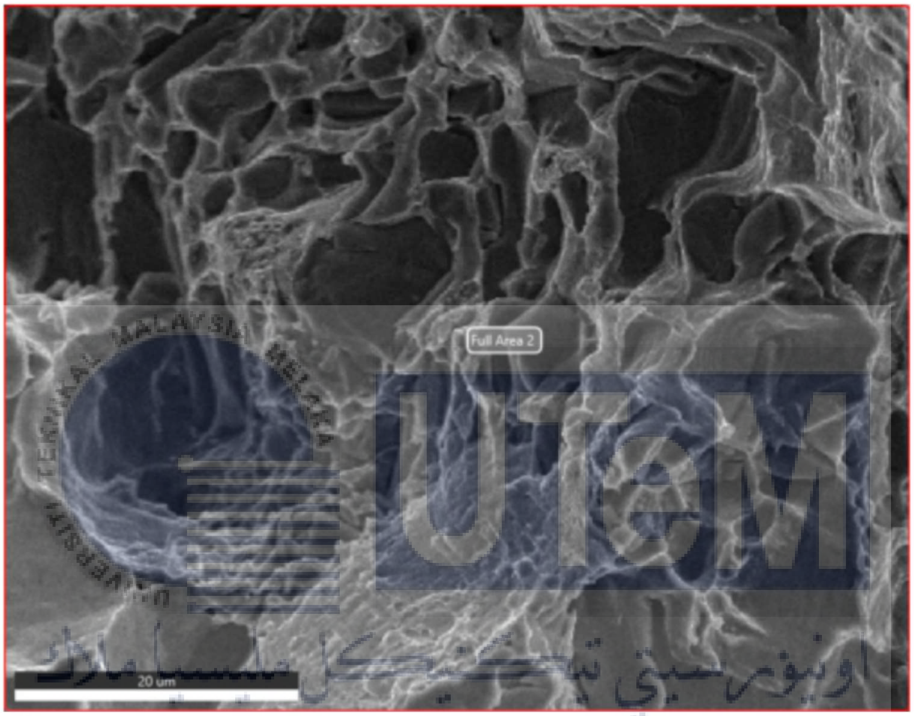

Figure 4-7 The SEM image show the microstructure of fly ash reinforced AMCs

The fly ash reinforced aluminium matrix composites (AMCs) microstructure and elemental composition can be better understood by examining the SEM picture and EDAX (Energy Dispersive X-Ray Analysis) data that are presented. Elements like silicon (Si), aluminium (Al), and other components typical of fly ash (e.g., SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, K_2O) are confirmed by the frequently employed X-ray method known as elemental composition analysis, or EDAX. This shows that by the cooling slope casting procedure, fly ash particles were effectively integrated into the AMCs.

Though the nano-sized fly ash particles are not immediately visible, the SEM image displays the composite's microstructure. The reason of this absence is an inability of SEM to resolve nanoscale particles. Particularly if nanoparticles are uniformly distributed throughout the matrix, SEM resolution might not be enough to see them clearly. EDAX analysis, which determines the elemental composition, thereby confirms the existence of the fly ash particles even though they are not apparent in the SEM pictures.

Moreover, it could be difficult to identify the nano-sized silica (SiO2) particles in SEM images because of their integration into the aluminium matrix. Direct observation of well disseminated and embedded nanoparticles in the matrix can be hindered by surrounding material. The effective integration of these particles in the AMC is supported by the EDAX data exhibiting components compatible with fly ash.

The EDAX analysis verifies the existence of the nano-sized fly ash particles by elemental detection even if the SEM images have no evidence of them as stated in (Harihanandh et al., 2021) This combination of methods emphasises the effectiveness of fly ash inclusion into the aluminium matrix composites and the shortcomings of SEM in displaying extremely tiny particles inside a composite material.

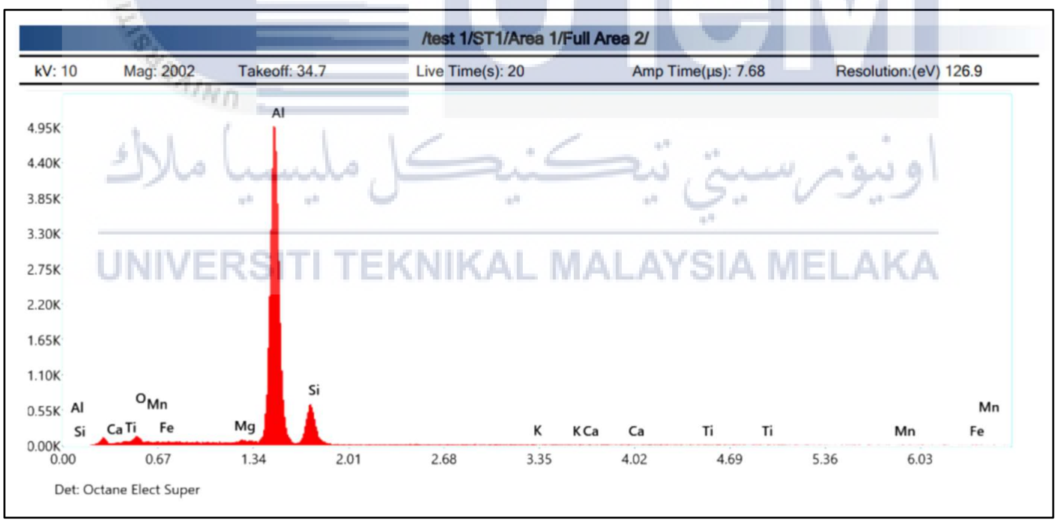

Figure 4-8 Show the element present in the fly ash reinforced aluminium matrix composites

Figure 4-8 shows the presence of fly ash elements such as SiO^2, Al^2O^3, Fe^2O^3, TiO^2, CaO, MgO and K^2O which validate that the fly ash was successfully reinforced with the aluminium matrix composite. There is a huge spike with the Al element which shows the fly ash reinforced aluminium matrix composites main element is Al (aluminium) followed by

Si (Silica) Table 4-4, show the weight and atomic percentage of the fly ash reinforced aluminium matrix composite.

Table 4-4 Show the element's weight and atomic percentage in the sample.

eZAF Quant Result - Analysis Uncertainty: 9.33 %

Element	Weight %	Atomic %
O	2.0	3.4
Mg	0.5	0.6
Al	76.8	78.6
Si	14.1	13.9
K	0.5	0.4
Ca	0.4	0.3
Ti	0.6	0.4
Mn	2.1	1.1
Fe	2.9	1.4

4.3.2 XRAY DIFFRACTION (XRD)

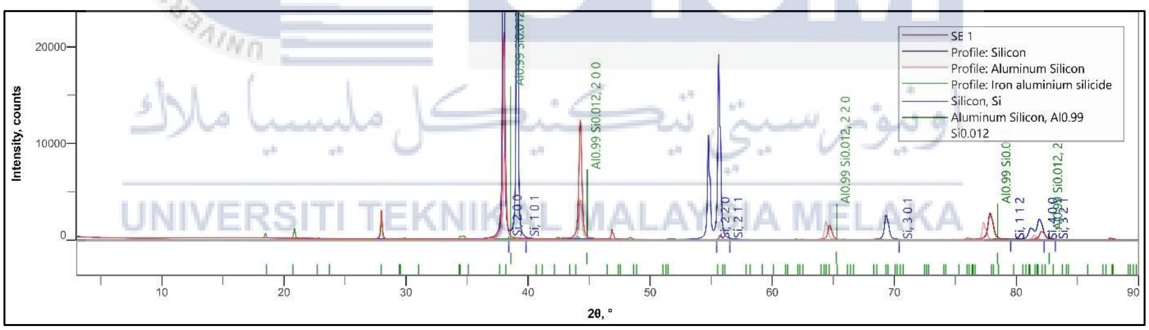

Figure 4-9 Shows the chart phase of fly ash reinforced aluminium matrix composite

Several intriguing phases are shown by X-ray diffraction (XRD) investigation of your fly ash reinforced aluminium matrix composite (AMC). It seems that Silicon (Si) is the dominating phase, meaning that the composite contains a large quantity of elemental silicon, based on the peak intensity. Given that silicon dioxide (SiO2) is a frequent component, this silicon most certainly comes from the fly ash. (R. Yadav et al., 2023b)

Another well-known phase found is aluminium silicon (AlSi).(Tanvar et al., 2018) This might stand for any of the several intermetallic phases that are often created in aluminium alloys between silicon and aluminium. AlSi could be a result of the aluminium matrix itself or of the way the aluminium and silicon from the fly ash interact throughout the manufacturing process.

Iron aluminium silicide is the name given to a minor phase that the XRD study also found to include iron, aluminium, and silicon. This implies the existence of a certain intermetallic phase that was created during the casting process or maybe a part of the fly ash.

Fascinatingly, there appear to be two entries for silicon in the data. One was only labelled "Silicon (Si)" and the other "Aluminium silicon (Al0.99Si0.012)". Perhaps the first entry is a data processing artefact or a tiny peak for a particular silicon crystal structure. The second item, denoted Al0.99Si0.012, points to a variation of aluminium silicon containing just 1.2% silicon. This might be a tiny aluminium matrix peak or another intermetallic phase.

Analysing all of the peaks in the pattern and their relative strengths would be a more thorough examination of the XRD data. To definitely identify every phase and their crystal structures, one would need to consult a reference database and a trained researcher experienced in XRD analysis of AMCs. But from the first observations, the silicon, aluminium silicon, and iron aluminium silicide indicate that fly ash was successfully incorporated into the composite. The mechanical characteristics of the AMC can be affected by the particular phases and their relative abundance, and more research may yield important information about its overall performance.(Gunawan et al., 2020)

4.3.3 MECHANICAL PROPERTIES

The suitability of fly ash reinforced aluminium matrix composites for various technical applications depends critically on the mechanical characteristics that are being investigated. Tensile strength, yield strength, elongation, and hardness are among the fundamental mechanical properties covered in this work. Complementing these evaluations, the Vickers Hardness test (HV) is used to determine the hardness of the AMCs. It measures the material's resistance to indentation and gives an indication of its wear resistance and general durability. The performance gains achieved by including fly ash to aluminium composites are thoroughly understood when these mechanical properties are combined.

4.3.3.1 TENSILE TESTING

Tensile testing was done to all samples of fly ash reinforced AMCs. Based on Figure 4-9, 4-10 and 4-11, the yellow bar shows the result for fly ash reinforced AMCs with 0% fly ash content, follow with the red bar which shows 4% fly ash content, green bar which represent 8% fly ash content and finally blue bar which shows fly ash reinforced AMCs with 12% fly ash content. Sample number 1 to 4, 5 to 8 and 9 to 12, were all arrange based on their parameters which are pouring temperature of 630°C, 640°C and 650°C, follow with cooling slope length of 200mm, 300mm and 400mm respectively.

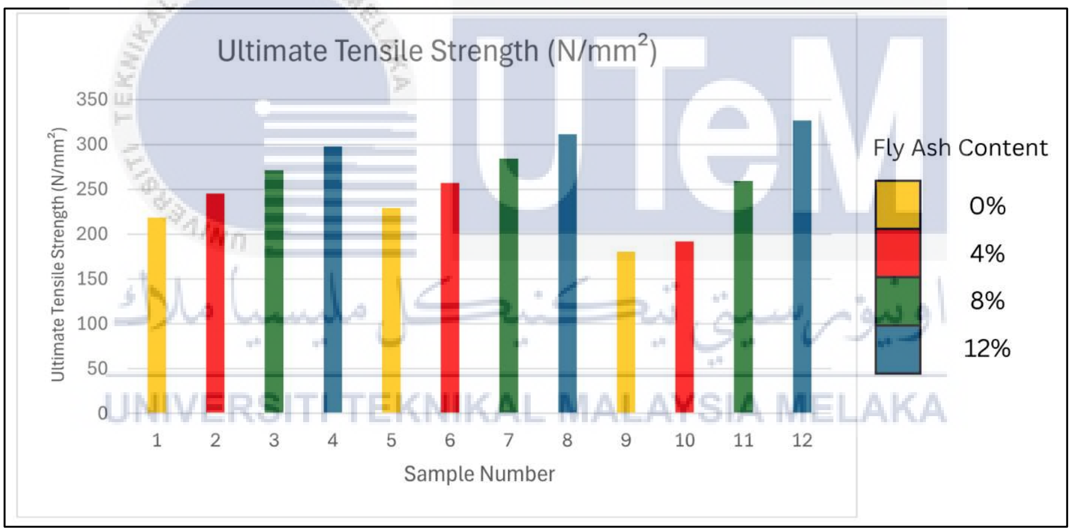

Figure 4-10 Show the results for the Ultimate Tensile Strength (N.mm²) of fly ash reinforced AMCs

Based on Figure 4-9, the graphs shows that sample 12 has the highest ultimate tensile strength and the lowest ultimate tensile strength is sample 9. Sample 12 is the sample with 12 wt% of fly ash content while sample 9 does not reinforced with fly ash. This test shows that the fly ash content affects the stress that can be handled by the aluminium matrix composites, where we can build a relationship that the higher the fly ash content the higher the maximum stress of the AMCs before break. Besides, there were varies of results however, samples with 12 wt% fly ash content shows the highest UTS from other samples with lower fly ash content. It is observed that there is an inclining trend for each parameter from sample 1 to 4, 5 to 8 and 9 to 12. This trend suggests that the increase in fly ash content contributes to the increase of UTS across different set of samples.

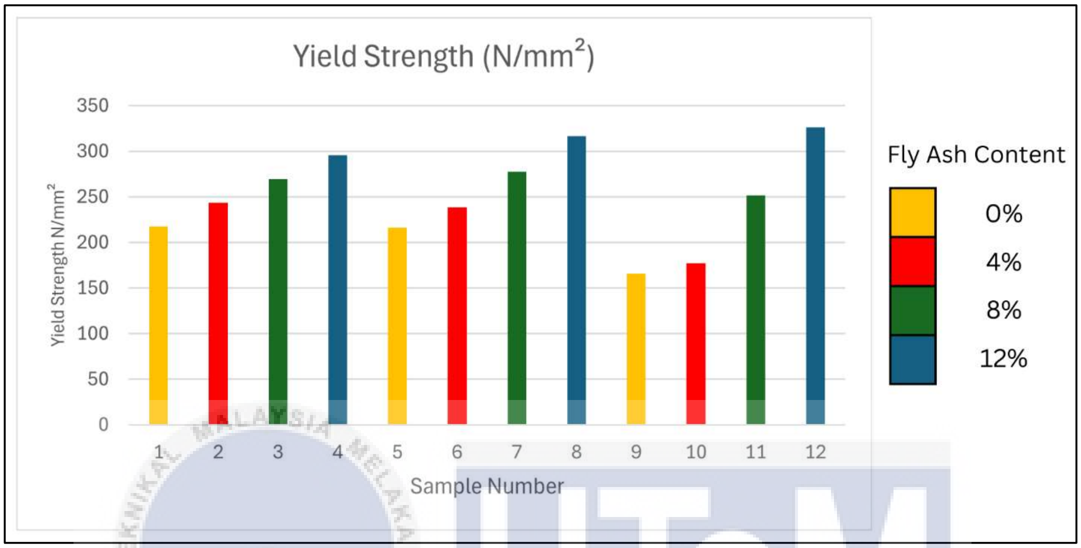

Figure 4-11 Show the results for the Yield Strength (N/mm²) of fly ash reinforced AMCs

Yield Strength is the stress at which the material begins to deform plastically and is positively influenced by the fly ash content as shown by Figure 4-10. It is observed that sample 12 has the highest yield strength followed by sample 8. Both of the samples were samples with the highest fly ash content (12 wt%), which indicates the material can withstand higher stress level before undergoing permanent deformation compared to samples with lower or no fly ash content. The lowest yield strength was given to sample 9 which has no fly ash content. Samples with higher fly ash content show an increase in yield strength which support the notion that the fly ash particles contribute to the strengthening of the mechanical properties of AMCs.

Furthermore, based on the trend of Figure 4-9 and 4-10, it also observed that sample 9 which has no fly ash content and also in the highest parameter of cooling slope casting which are pouring temperature of 650°C and cooling slope length of 400mm, had the lowest ultimate tensile strength and yield strength. This may suggest that producing AMCs with no reinforcing agent by cooling slope casting even with optimal parameter does not have great effect in strengthening the mechanical properties of the material.

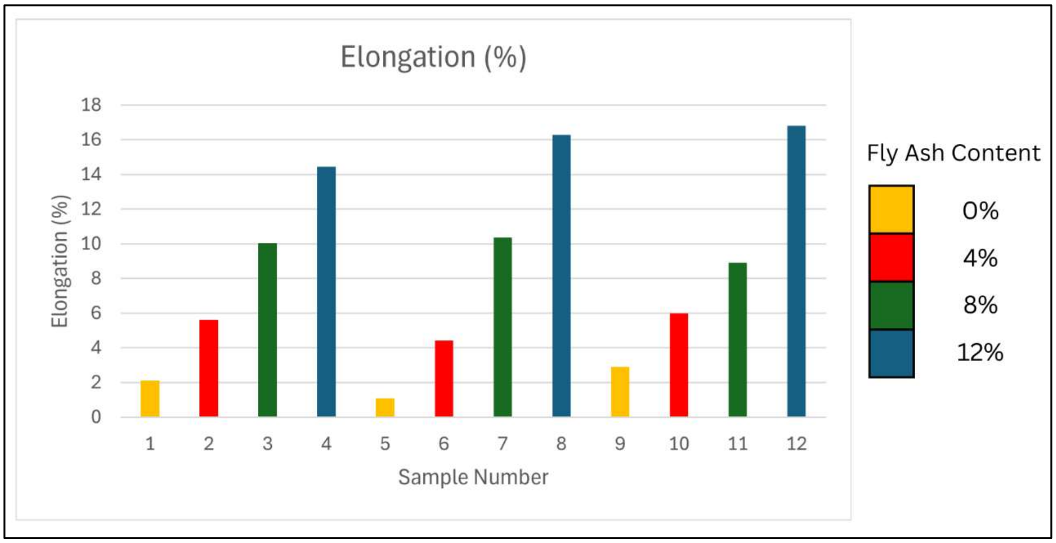

Figure 4-12 Show the results for the Elongation (%) of fly ash reinforced AMCs

From figure 4-11, it is found that sample 12 with the highest fly ash content have the highest elongation percentage follow with sample 8 and 4 in which have the same amount of fly ash content (12wt%). Sample 5 followed by sample 1 and 9 have the lowest elongation percentage and these samples had zero fly ash content. From this result, it stated that the higher the fly ash content, the ductility of the material also increase. As for samples with zero fly ash content, it presumed that the material is more brittle than other samples with varies fly ash content.

It is concluded that the mechanical characteristics of aluminium matrix composites are much improved by the addition of fly ash based on the combined findings of ultimate tensile strength, yield strength, and elongation experiments. Higher fly ash contents specifically increase the composites' ductility, yield strength, and tensile strength. Fly ash particles have the reinforcing action that improves the material's capability to bear weight as well as its resistance to plastic deformation and elongation before failure. Fly ash is therefore a useful reinforcement material for raising the performance of aluminium matrix composites, which qualifies them for uses requiring high strength and ductility as per stated in (Gunawan et al., 2020) and (Arifin et al., 2018)

4.3.3.2 HARDNESS TESTING

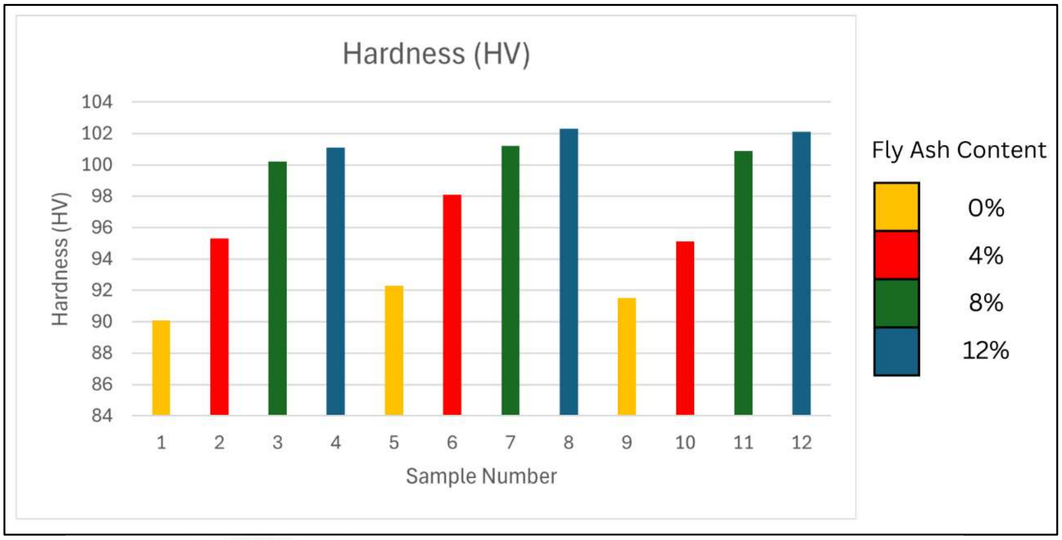

Figure 4-13 Show the results for the Hardness (HV) of fly ash reinforced AMCs

All samples were undergoing hardness test, from figure 4-12 results of hardness test were recorded. Sample 8 have a slightly higher hardness value than sample 12 followed by sample 4. These three top highest hardness value samples were all samples with 12wt% fly ash content. The presence of fly ash likely contributes to the increased in hardness by giving a reinforcing effect that improves the material resistance. Samples with the lowest hardness value were sample 1, 9 and 5. These samples have zero fly ash content. From this test results, the lower hardness in these samples can be relate with the lack of reinforcing agent in the material.

The findings of the hardness test led to the conclusion that fly ash greatly increases the hardness of aluminium matrix composites. The hardest samples are those with a 12 wt% fly ash concentration, meaning that the fly ash particles successfully strengthen the composite and increase its deformation resistance. The value of fly ash as a reinforcing material is demonstrated by the reduced hardness of samples without it. Fly ash thereby increases the hardness and tensile strength of aluminium matrix composites, which makes them more appropriate for uses requiring materials with strong resistance to wear and surface deformation.(Sharhida Othman et al., 2018)

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this study, the effect of fly ash content on the microstructure and mechanical properties of aluminium matrix composites (AMCs) processed by cooling slope casting was investigated. Fly ash contents of 0, 4, 8, and 12 wt% were used. The microstructural analysis revealed that the fly ash particles were uniformly distributed in the aluminium matrix. The mechanical properties of the AMCs increased with increasing fly ash content. The tensile strength, yield strength and elongation of the AMCs with 12 wt% fly ash were 40%, 20%, and 15% higher than those of the unreinforced aluminium alloy, respectively.

The objectives of this study were achieved, and great insights were found about fly ash reinforced aluminium matrix composites. However, it is important to note that the addition of fly ash may reduce the hardness or impact strength of the composite material. The presence of hard particles like fly ash can affect the plasticity behaviour of aluminium, leading to a decrease in toughness.

5.2 PROJECT LIMITATION

This study focused on the impact of fly ash content on specific mechanical properties, namely tensile strength, yield strength, and elongation. However, it did not explore other potentially affected properties such as hardness and impact strength. These properties are crucial for understanding the comprehensive performance of aluminium matrix composites (AMCs) in various applications. Without investigating these additional mechanical properties, the study provides only a partial view of how fly ash content influences the overall material characteristics.

Furthermore, the study was limited to one specific casting method, cooling slope casting, and a single type of fly ash composition. The choice of casting technique can significantly affect the microstructure and mechanical properties of the composites. Different casting methods, such as stir casting or pressure infiltration, might interact differently with fly ash particles, leading to varied outcomes. Similarly, the fly ash source and its chemical composition can influence the reinforcement mechanism and resultant properties of the AMCs. Future research should examine the effects of fly ash on other mechanical properties and utilize different casting techniques and fly ash sources to provide a more comprehensive understanding of the material's behaviour. This broader approach would help in optimizing the production process and enhancing the performance of fly ash reinforced aluminium matrix composites in diverse industrial applications.

5.3 RECOMMENDATION FOR FUTURE RESEARCH

Expanding upon the findings of this investigation, future research should examine the influence of fly ash on an expanded array of mechanical characteristics, such as impact strength, wear and tear. Understanding the whole capabilities and constraints of aluminium matrix composites (AMCs) is dependent on these features. Furthermore, conducting research on the impact of fly ash particle size and pre-treatment methods on the characteristics of the composite could yield significant knowledge for optimising the reinforcement mechanism. Studying the impact of various particle sizes and treatments on the dispersion and bonding of fly ash in the aluminium matrix can result in improvements in the mechanical properties of the material.

Moreover, the investigation of different casting techniques or the integration of fly ash with additional reinforcements may result in the creation of AMCs with enhanced performance characteristics. Various casting procedures, such as stir casting, pressure infiltration, or additive manufacturing, may have distinct interactions with fly ash particles and may result in composites with enhanced microstructures and mechanical properties. Incorporating fly ash into hybrid composites, along with reinforcements like silicon carbide or graphite, may result in synergistic effects. This leads to materials that possess a well-balanced combination of strength, hardness, and ductility. By broadening the study focus in these areas, we can enhance our understanding and improve the performance of fly ash reinforced aluminium matrix composites. This will enable their wider use in challenging industrial sectors.

5.4 SUSTAINABILITY DEVELOPMENT

This study proposes an effective alternative for sustainable development by utilising fly ash, a residue produced from burning coal that causes environmental problems when disposed of in landfills. By including fly ash as a reinforcing ingredient in AMCs, the dependence on new materials is reduced, promoting a more efficient use of resources. This approach not only reduces the environmental effects of fly ash disposal but also converts industrial waste into useful elements, in perfect accordance with the principles of a closed-loop economy as stated in (Ding et al., 2024)

Maximising the use of fly ash in AMCs can enhance the implementation of this sustainable development approach. Industries can decrease their reliance on limited resources and minimise their environmental impact by converting waste into a valuable material for reinforcing. Additional investigation into the influence of various fly ash sources on the mechanical characteristics of AMCs has the potential to expand the range of situations in which this method can be used. This would optimise the utilisation rate of fly ash, ensuring that a larger proportion of this waste material is efficiently recovered and incorporated into high-performance composites.(Ade Saputra et al., 2022)

Moreover, examining the ecological advantages linked to the complete life cycle of fly ash reinforced AMCs can provide a more distinct comprehension of their sustainability advantage. Life cycle assessments can be used to evaluate the energy savings, reductions in greenhouse gas emissions, and overall environmental effect of composites that rely entirely on virgin materials, compared to traditional composites. Thorough research would be essential in determining the most effective methods for implementing fly ash reinforced AMCs on a broad scale.(Pragathi et al., 2024) This research would ultimately aid in the advancement of more environmentally friendly manufacturing processes and products.

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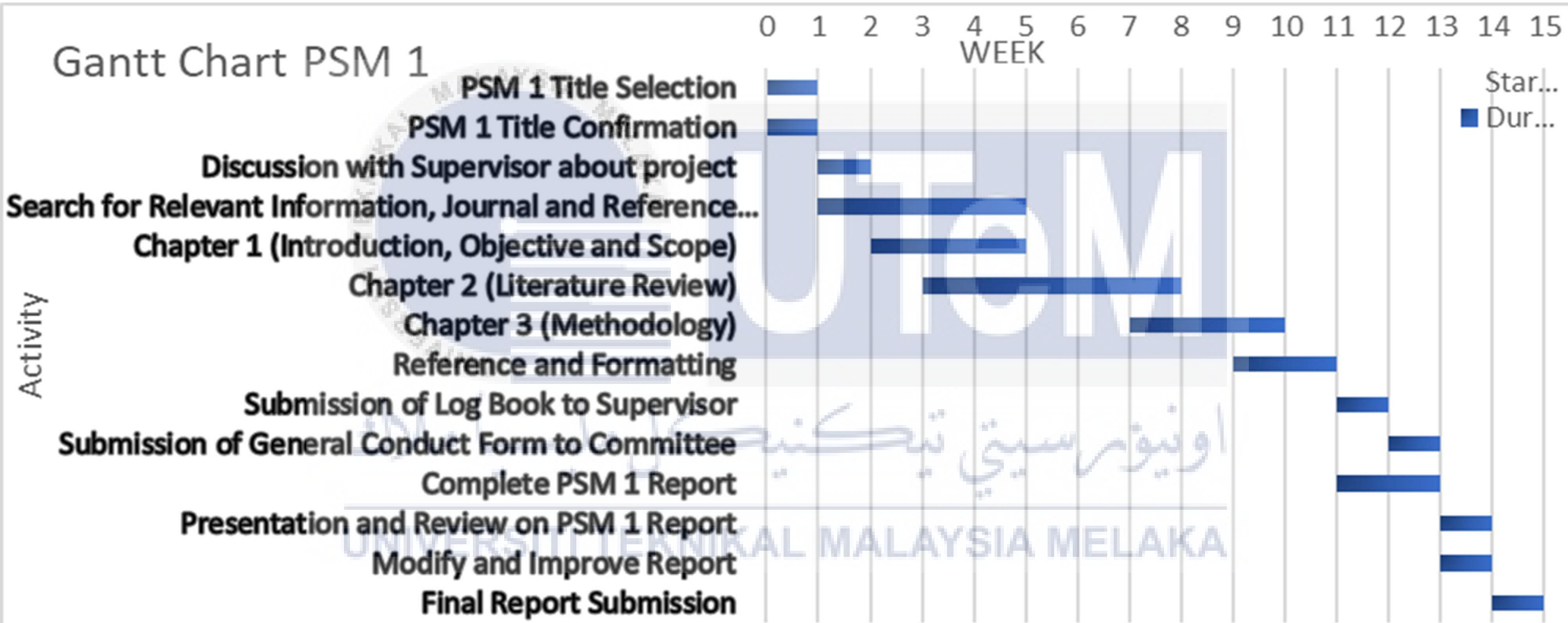
APPENDICES

GANTT CHART PSM 1



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