

EVALUATION OF MICROSTRUCTURE, MECHANICAL, AND CORROSIVE BEHAVIOUR OF ALUMINIUM METAL MATRIX COMPOSITE

PROJECT REPORT

Submitted by

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the APJ Abdul Kalam Technological University

in partial fulfillment of the requirements for the award of Degree

of

Master of Technology

In

Computer Integrated Manufacturing



DEPARTMENT OF MECHANICAL ENGINEERING

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DECLARATION

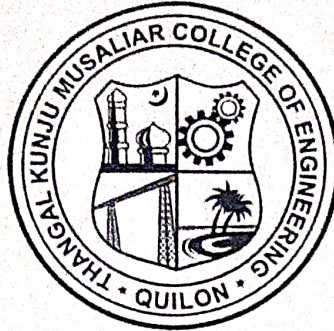
I Akhil H, hereby declare that the project report entitled “ Evaluation of Microstructure, Mechanical, and Corrosive Behaviour of Aluminium Metal Matrix Composite ”, submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Asst.Prof Rakesh Pillai R., Department of Mechanical Engineering, TKMCE Kollam. This submission represents my ideas in my own words and where ideas or words of others have been included. I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

This is to certify that the project report entitled '**Evaluation of Microstructure, Mechanical, and Corrosive Behaviour of Aluminium Metal Matrix Composite**' submitted by **AKHIL H, TKM21MECI02** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Computer Integrated Manufacturing, Department of Mechanical Engineering is a bonafide record of the project work carried out by him under our guidance and supervision. This report in any form has not been submitted to any other University or institute for any purpose.

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ABSTRACT

The aim of this research project is to examine the results of using stir casting to incorporate boron carbide (B_4C) and coconut shell ash as reinforcements into an Al1350 alloy (aluminium wire) matrix. To improve its properties, the hybrid composite was created with a weight percentage of 1.25. A number of tests are performed, including the Charpy impact test to gauge the material's impact resistance, microstructure analysis using a Scanning Electron Microscope (SEM) to examine fractured parts, the Rockwell hardness test, the measurement of grain size and porosity distribution using an optical microscope, and the electrochemical corrosion test in a saltwater environment. The findings show that the composite's properties have changed significantly. Impact energy has been noticeably reduced by 16%, which suggests a decline in the capacity to withstand sudden impact loads. The corrosion rate has significantly decreased by 26.9%, demonstrating the composite's improved corrosion resistance. A 20% increase in hardness is also present, indicating increased resistance to localised deformation. Additionally, there is a small 3.7% decrease in density, which suggests a possible weight reduction while maintaining desired properties. These results contrast with the Al1350 base matrix alloy's properties. It can be assumed that the base matrix's corrosion resistance and hardness have improved as a result of the addition of B_4C and coconut shell ash reinforcements. However, the impact strength has slightly decreased. The comprehensive analysis of the composite's properties can be very advantageous for applications where enhanced corrosion resistance, increased hardness, and weight reduction are desired.

Keywords: Boron Carbide (B_4C), coconut shell ash, Al1350 (Aluminium wire), Charpy Impact Test, Optical microscope, Rockwell Hardness Test, Electrochemical Corrosion Test.

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ABBREVIATIONS

PMC	Polymer matrix composites
MMC	Metal matrix composites
CMC	Ceramic matrix composite
AMC	Aluminium matrix composite
CNT	Carbon nanotubes
CSA	Coconut shell ash
FA	flyash
RHA	Rice husk ash
HAMC	Hybrid aluminium matrix composites
CSFA	Coconut shell flour ash
RTM	resin transfer moulding
VARTM	Vacuum assisted resin transfer moulding
VIP	Vacuum infusion process
EDM	Electrical discharge machining
CNC	Computer numerical control
ASTM	American society for testing and materials
EIS	Electro chemical impedance spectroscopy
LPR	Linear polarization resistance

CHAPTER 1

INTRODUCTION

1.1 MATERIAL SCIENCE

Material science is a multidisciplinary field that explores the properties, structure, and performance of materials. It encompasses the study of various types of materials, including metals, ceramics, polymers, semiconductors, and composites.

The primary goal of material science is to understand how the atomic and molecular structure of materials influences their macroscopic properties. By gaining this knowledge, scientists and engineers can develop new materials with specific properties and improve existing materials for various applications.

Material scientists investigate the composition, processing, and structure of materials, as well as their mechanical, thermal, electrical, magnetic, and optical properties. They also study how materials interact with their environment, such as their response to stress, temperature, humidity, and chemical exposure.

This field has numerous practical applications, including the development of advanced materials for industries like aerospace, automotive, electronics, energy, medicine, and many more. Material scientists employ a range of techniques and tools, such as microscopy, spectroscopy, X-ray diffraction, and computational modeling, to analyze and manipulate materials at the atomic and molecular levels.

Overall, material science plays a crucial role in advancing technology, improving the performance and sustainability of materials, and driving innovation in various industries.

1.2 COMPOSITES

Engineered materials known as composites are made up of two or more separate constituent materials that have radically diverse physical or chemical characteristics. A final product with

improved qualities and performance attributes relative to its constituent parts is produced by combining these constituent materials.

A reinforcing phase, often known as the reinforcement, and a matrix phase that envelops and binds the reinforcement together commonly make up composite materials. While the matrix phase functions to transfer stress between the reinforcement and offer environmental protection, the reinforcement phase gives the material strength and rigidity.

The reinforcement phase may consist of fibres, particles, or flakes manufactured of aramid, carbon, glass, or even natural fibres like hemp or bamboo. The matrix material, which is often a polymer, ceramic, or metal matrix, contains these fibres embedded inside it. The matrix material distributes the weight over the composite structure, binds the reinforcement together, and shields it from harm.

The optimisation of certain attributes including strength, stiffness, lightweight, durability, corrosion resistance, thermal conductivity, and electrical conductivity is made possible by the mixing of several components in composite materials. Aerospace, automotive, construction, marine, sports equipment, and many more industries use composites because their special qualities make them superior to more conventional materials like metals or plastics.

1.3 HISTORY OF COMPOSITES

Thousands of years have passed since the invention of composite materials. Throughout history, civilizations have used the idea of combining various materials to produce a new substance with improved qualities. The development of composite materials can be summarised as follows:

Ancient Civilizations: Composite materials have been used as far back as ancient civilizations can be traced. Faience is a type of composite material that was employed, for instance, by the ancient Egyptians to make beautiful jewellery and ceramics. Powdered quartz or sand was combined with various metallic oxides and fired to create faience.

Middle Ages: Composite materials were utilised in a number of Middle Ages applications. The creation of laminated bows for archery using wood and animal glue is one prominent example.

These bows were stronger and more resilient than solid hardwood bows.

Renaissance and Enlightenment: The creation of composite materials was aided by scientific and technological advancements made throughout the Renaissance and Enlightenment periods. Making plywood, which entails using glue to bind together thin layers of wood, is one noteworthy example. In the creation of furniture and for construction, plywood became widely employed.

Industrial Revolution: Composite materials saw considerable breakthroughs throughout the Industrial Revolution in the 18th and 19th centuries. For instance, Joseph Monier's development of reinforced concrete in the 1860s completely altered the construction industry. Concrete that had been strengthened with steel bars or mesh was more durable and strong.

20th Century: Composite materials made significant advancements throughout this time period. Bakelite, the first synthetic material, was created in the early 1900s. By combining phenol and formaldehyde to create bakelite, numerous composite materials may be mass produced.

Second World War: The exigencies of the Second World War hastened the development and application of composite materials. During this time, fiberglass—a material made of glass fibres and a polymer resin—was widely used. Fibreglass was a good choice for aircraft and other military applications because of its great strength-to-weight ratio and resistance to corrosion.

Modern Era: In recent decades, composite materials have been widely used in a variety of sectors, including sports, automobile, aircraft, and the maritime industry. Due to their outstanding strength and lightweight design, carbon fibre composites—which are composed of carbon fibres embedded in a polymer matrix—have grown in popularity.

Currently, composite materials are developing as a result of continual research and development aimed at enhancing their characteristics, production methods, and sustainability. They are used in a variety of products, such as wind turbine blades, sports equipment, automobile parts, and aerospace components.

1.4 TYPES OF COMPOSITES MATERIALS

Materials that combine two or more unique components with disparate physical or chemical characteristics are known as composites. When these elements are mixed, a brand-new substance is produced that has better qualities than the sum of its parts. Here are a few popular composite materials:

- **Fiber-Reinforced Composites :** Composite materials that have fibre reinforcement make up fiber-reinforced composites. Materials like carbon, glass, aramid (like Kevlar), or natural fibres like bamboo can be used to create the fibres. Fiber-reinforced composites are well known for having a high strength-to-weight ratio and are frequently utilised in the production of sports equipment, automobiles, and aerospace products.
- **Polymer Matrix Composites (PMCs):** Polymers like nylon, polyester, or epoxy make up the matrix of PMCs, which are composites. Fibres, particles, or sheets can be used as reinforcement. Due to their light weight, resistance to corrosion, and flexibility in design, PMCs are well suited for a variety of applications, including boat hulls, wind turbine blades, and automotive parts.
- **Metal matrix composites (MMCs):** MMCs are reinforced with ceramic, metallic, or carbon fibres and contain a metal matrix material, such as aluminium, titanium, or magnesium. MMCs can be used in the aerospace, defence, and electronics industries because of their high strength, stiffness, and good heat conductivity.
- **Ceramic fibres or ceramic particles** are used to reinforce ceramic matrix composites (CMCs), which are composite materials. High strength, thermal stability, and wear resistance are only a few of its exceptional high-temperature characteristics. CMCs are used in cutting tools, heat exchangers, and aircraft engines.
- **Sandwich Composites:** These composites have two outer layers (facial sheets) consisting of aluminium, fibreglass, carbon fibre, or a lightweight core material (such foam or a

honeycomb structure). Sandwich composites are ideal for uses like aeroplane panels, boat hulls, and wind turbine blades because they have great stiffness and strength while being lightweight.

- **Natural Fibre Composites:** In these composites, the reinforcing comes from natural fibres that are obtained from plants (like jute, flax, or hemp) or animals (like wool or silk). Natural fibre composites are environmentally friendly because they are renewable and biodegradable. They are utilised in furniture, interior elements, and packaging materials, among other things.

These are only a few types of composites; each type has numerous variations and subtypes. Composites are adaptable materials in many industries because of the vast range of qualities they offer and the ability to be customised for certain purposes.

1.5 ALUMINIUM BASED COMPOSITES

Aluminium composites, also known as aluminium matrix composites (AMCs), are cutting-edge materials that combine aluminium's lightweight characteristics with reinforced materials' increased strength and stiffness. These composites are made by incorporating a secondary material—such as fibres, ceramics, or other particles—into an aluminium matrix.

The exceptional strength-to-weight ratio of aluminium composites is one of their main benefits. These composites, which can outperform pure aluminium in terms of mechanical properties, combine high-strength materials with an aluminium matrix. They are therefore perfect for industries like aerospace, automotive, and sporting goods where lightweight design and structural integrity are essential requirements.

The specific properties of aluminium composites are influenced by the reinforcing materials used in them. For example, ceramic particles such as silicon carbide or alumina can improve the

composite's hardness and wear resistance. On the other hand, adding carbon or glass fibres boosts the composite's stiffness and tensile strength, enhancing its resistance to mechanical stresses. The preferred properties and the particular application requirements determine the choice of reinforcing materials.

Due to the inherent qualities of aluminium, aluminium composites also offer excellent thermal and electrical conductivity. They are thus suitable for applications requiring effective heat dissipation and electrical conduction, such as heat sinks, electronic packaging, and power transmission.

Typically, techniques like powder metallurgy, liquid metal infiltration, or solid-state processing are used to create aluminium composites. These procedures make sure that the matrix and the reinforcing materials are properly bonded, creating a composite structure that is homogeneous and well-integrated.

Aluminium composites produce versatile, high-performance materials by fusing aluminium's light weight with the stiffness and strength of reinforcing materials. Aluminium composites are used in a variety of industries and help advance engineering and technology thanks to their exceptional strength-to-weight ratio, thermal conductivity, and adaptability.

1.6 HYBRID COMPOSITES

A form of composite material known as a hybrid composite is made up of two or more different types of reinforcing fibres enmeshed in a single matrix material. In other words, it blends the characteristics of various fibres to produce a composite material that performs better all around.

A matrix material, such as epoxy, polyester, or nylon, is typically coupled with two or more types of fibres, such as carbon fibres, glass fibres, aramid fibres, or natural fibres. The final composite material's intended qualities will determine the fibres and matrix to use.

Utilising several fibre kinds allows designers to benefit from each one's unique advantages and

qualities. For instance, glass fibres have good impact resistance while carbon fibres are renowned for their tremendous strength and stiffness. It is feasible to create a material that combines high strength, stiffness, and impact resistance by mixing these fibres in a hybrid composite.

Applications for hybrid composites include construction, sports equipment, automotive, aerospace, and the marine industry. To fulfil the needs of a particular application, a particular fibre and matrix material combination can be customised to offer greater mechanical capabilities, weight savings, increased durability, or other desired qualities.

Overall, hybrid composites provide a method for improving the performance of composite materials by utilising the special qualities of many fibre types, producing materials with higher strength, stiffness, impact resistance, and other desirable traits.

1.6.1 Advantages of hybrid composites

- (i). Tailored properties: Properties that can be adjusted and tailored to fit particular needs are possible with hybrid composites. The performance of the material can be enhanced for a specific application by choosing various reinforcement and matrix combinations. When creating materials for intricate and demanding applications, this flexibility in property tweaking is very useful.
- (ii). Weight reduction : Weight reduction advantages may be provided by hybrid composites. A high strength-to-weight ratio can be attained by using lightweight reinforcements, such as carbon fibres or aramid fibres, in conjunction with other materials. This is especially helpful in fields like aerospace and automobiles, where losing weight can increase performance and fuel economy.
- (iii). Damage tolerance: Compared to single-component composites, hybrid composites may have better damage tolerance. Materials that are better able to resist and redistribute applied loads, as well as endure impact or other types of external damage, can be produced by

combining several reinforcements or matrices. This can improve the overall toughness and security of hybrid composite structures or parts.

- (iv). Cost-effectiveness: Hybrid composites may occasionally be more affordable. It might be possible to lower the composite's overall cost while keeping its desirable qualities by blending several elements. Additionally, hybrid composites allow for the blending of more expensive materials with less expensive ones, balancing performance and price.
- (v). Multifunctionality: By combining materials with various properties, hybrid composites can offer multifunctional characteristics. For instance, it is conceivable to incorporate materials with thermal management capabilities or structural reinforcement with conductive qualities. This makes it possible to create composite materials that perform many tasks in a single component, increasing their versatility and efficiency.

In general, hybrid composites have a number of benefits, including as increased mechanical properties, customised characteristics, weight reduction, improved damage tolerance, cost effectiveness, and multifunctionality. Hybrid composites are appealing for a range of applications in industries like aerospace, automotive, construction, and sports equipment because of these advantages.

1.6.2 Applications of hybrid composites

Industry of aerospace: Due to its light weight, high strength-to-weight ratio, and superior fatigue resistance, hybrid composites are widely used in aerospace applications. They contribute to increased performance and fuel efficiency by being employed in aircraft structures, wings, fuselages, control surfaces, and interior components.

- (i). Automotive industry: To reduce vehicle weight while retaining structural integrity and crashworthiness, hybrid composites are being used more and more in the automotive industry. They improve fuel efficiency and cut emissions and can be found in body panels,

chassis parts, interior components, and suspension systems.

- (ii). Renewable energy: To improve the structural integrity, longevity, and performance of solar panels and wind turbine blades, hybrid composites are used. enhanced fatigue life, lower maintenance requirements, and enhanced resistance to adverse weather conditions are all made possible by the mix of various fibres and matrix materials.
- (iii). Sports and recreation: Hybrid composites are widely utilized in the production of sporting products such skis, snowboards, bicycles, golf clubs, tennis rackets, and golf balls. These materials provide greater stiffness, strength, and impact resistance, which enhances durability and performance.
- (iv). Marine industry: Hybrid composites are used in the marine industry, particularly in the construction of boats and ships. They are ideal for hulls, decks, masts, and other structural components because of their high strength, longevity, and resistance to corrosion. Additionally, the buoyancy and hydrodynamics of boats can be improved using hybrid composites.
- (v). Infrastructure and construction: Hybrid composites are used in the construction sector for a variety of applications. They have excellent strength, corrosion resistance, and lightweight qualities and can be utilized in pipes, bridges, reinforcing bars, and structural parts.
- (vi). Defence and military: Lightweight armour, ballistic protection, and structural components in cars, planes, and body armour are all uses for hybrid composites in the defence and military. When compared to conventional materials, these materials offer better protection and performance.
- (vii). Medical devices: Hybrid composites are used in the production of surgical instruments, implants, and prosthetics as well as orthotics and prosthetic limbs. Better patient outcomes and higher quality of life are made possible by their outstanding biocompatibility, strength, and flexibility.

1.7 DIFFERENT FABRICATION METHODS

Aluminium metal matrix composites (AMMCs) are made using a variety of fabrication techniques, each of which has its own benefits and drawbacks. Stir casting involves mechanically stirring ceramic or metallic particles into a molten aluminium matrix. This is a widely used technique.

Utilising techniques like hot pressing and hot isostatic pressing, powder metallurgy consolidates reinforcements and powdered aluminium to provide precise control over reinforcement distribution. Squeeze casting ensures excellent bonding by using high pressure to inject molten aluminium into a preform containing reinforcements. By creating reinforcements within the molten aluminium matrix, in-situ synthesis creates a consistent distribution of tiny particles. Spray deposition uses high-velocity jets to deposit molten aluminium and reinforcement powders, creating composite coatings with excellent adhesion that enhance overall performance.

By increasing strength, lowering weight, and enhancing overall performance, these fabrication techniques enable the production of AMMCs tailored to specific applications, such as aerospace, automotive, and structural components.

(i). Stir casting :A common fabrication method for aluminium metal matrix composites is stir casting. In this method, a molten aluminium alloy is mixed with the reinforcement material (such as ceramic particles, fibres, or whiskers) and stirred to ensure a uniform distribution. The final product is created by solidifying the molten composite.

Benefits: Stir casting has a number of benefits, such as simplicity, affordability, and the ability to produce a variety of composite shapes. It enables the tailoring of mechanical

properties by allowing the incorporation of various types and volume fractions of reinforcements. The reinforcement and matrix are well bonded during stir casting, which enhances load transfer.

Merits: Stir casting has some drawbacks despite its benefits. Given the possibility of agglomeration and settling, the dispersion of reinforcements can be difficult. Reduced mechanical properties and a non-uniform distribution may result from this. Additionally, the stirring procedure might add oxide inclusions and gas porosity, which would impact the composite's quality. Due to the limitations of the method, producing large and intricately shaped components design restrictions on moulds.

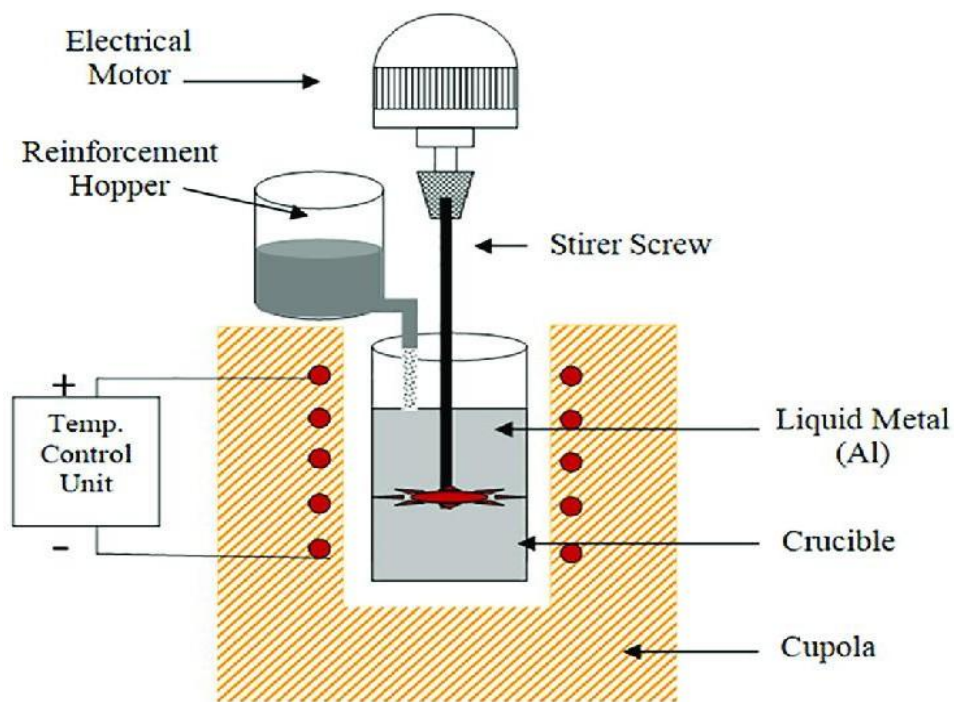


Figure 1.1 schematic representation of Stir casting-[21]

- (ii). Squeeze Casting: Squeeze casting, also referred to as liquid metal forging, is a process that creates AMMCs by simultaneously applying pressure and heat. In this method, the reinforcement material is placed inside a preheated die cavity before the molten metal is poured into the cavity. The composite is then solidified under high pressure and temperature

conditions by applying pressure. Squeeze casting has a number of benefits. It allows for excellent control over the distribution of reinforcement materials, producing a microstructure that is uniform and finely dispersed. High pressure that exists during solidification improves the interface between the matrix and the reinforcement, which results in better mechanical properties. With good dimensional accuracy, squeeze casting can create components with complex shapes. Merits: The main drawback of squeeze casting is that it is more expensive than other fabrication methods. Longer cycle times and specialised equipment are needed for the process. The largest size of the components that can be produced is also restricted.

improves the matrix-reinforcement interface, which has a positive impact on the mechanical properties. With good dimensional accuracy, squeeze casting can create components with complex shapes.

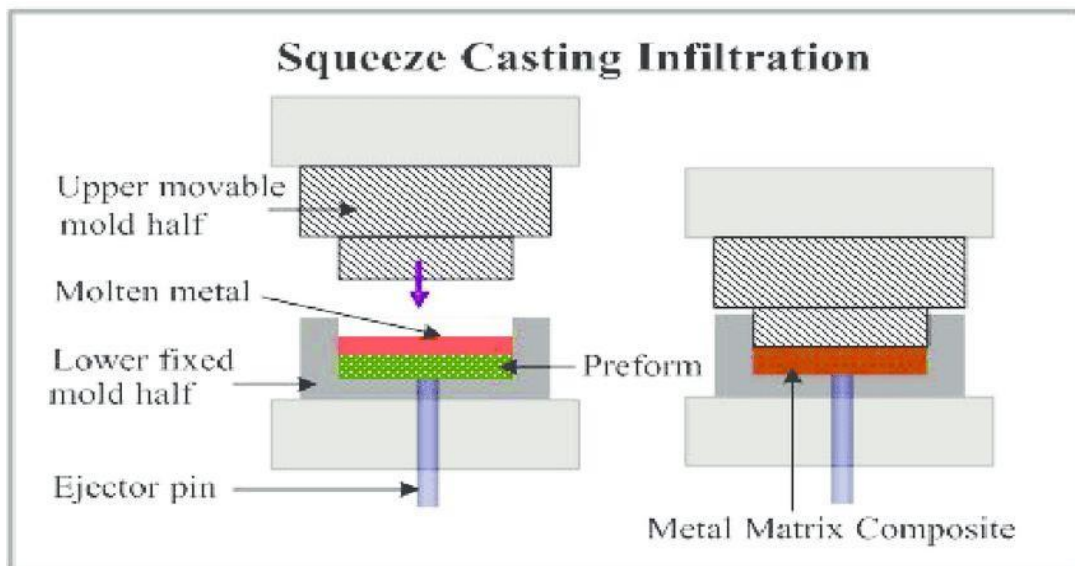


Figure 1.2 Schematic representation of squeeze casting-[22]

(iii). Vacuum Die casting : During the casting process, vacuum die casting involves removing air and gases from the mould cavity. The AMMC is created by injecting the molten aluminium

alloy into the mould while it is under vacuum. The advantages of vacuum die casting over traditional die casting techniques include decreased porosity and improved surface finish. Higher density and improved mechanical properties are produced as a result of the vacuum environment's contribution to reducing gas-related defects. The method also makes it possible to produce intricately shaped components with high dimensional accuracy.

However, vacuum die casting has some restrictions. It costs more than conventional die casting and necessitates specialised equipment. It has size and weight restrictions as well.

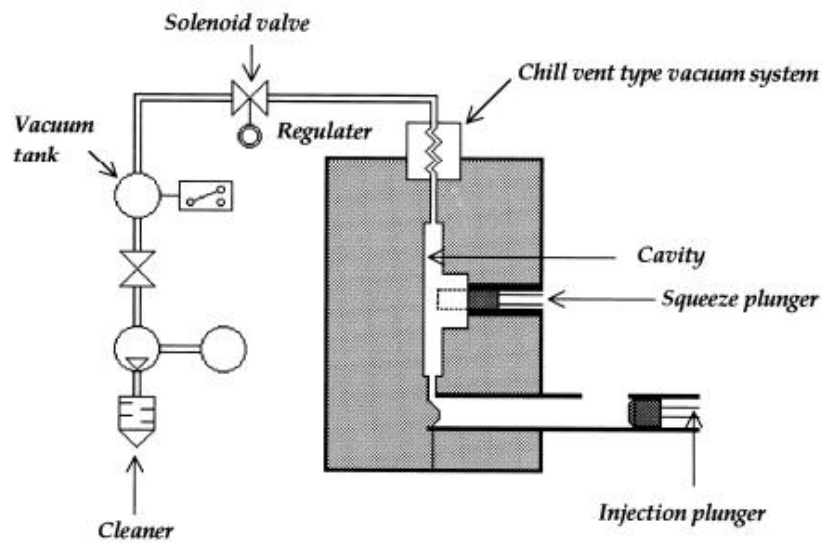


Figure 1.3 Schematic representation of Vacuum Die casting-[23]

- (iv). Powder metallurgy : A manufacturing technique called powder metallurgy is used to create composite materials with distinctive qualities and uses. This procedure involves carefully mixing fine metal powders with other additives, such as ceramic or polymer particles, to produce a homogeneous mixture. A green compact is created by pressing this mixture firmly together under high pressure. The metal particles in the green compact are then sintered at high temperatures, where they unite to form a solid, dense composite material. The powder metallurgy process has a number of benefits for producing composite materials. It makes it possible to precisely control the makeup and distribution of the

reinforcing particles within the matrix material, resulting in the creation of composites with specific properties. Additionally, the incorporation of various materials—including those with naturally disparate melting points or incompatible properties—is made easier by the use of powders. With better strength, wear resistance, thermal conductivity, and other desired properties, composite materials can be produced as a result.

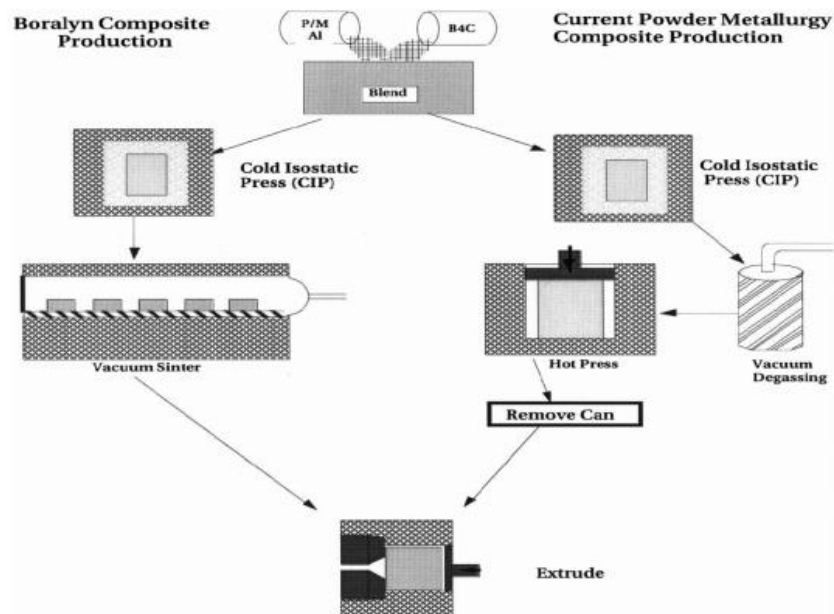


Figure 1.4 Schematic representation of Powder metallurgy casting-[24]

- (v). Diffusion bonding : In the production of composites, diffusion bonding is a common technique for fusing composite materials together. It is a form of solid-state welding in which the diffusion of atoms across the bonding interface is aided by the application of heat and pressure. The composite materials are in this process carefully aligned and brought together under controlled circumstances. To ensure close contact between the mating surfaces, pressure is first applied to start the bonding process. The materials are then heated to a temperature that is typically below their melting point. The increased temperature encourages atom diffusion, enabling atoms to move across the interface and form atomic

bonds. Diffusion bonding's capacity to create high-strength joints without the use of mechanical fasteners or adhesives is one of its main benefits. By using this technique, seamless composite structures with strong structural integrity can be produced. Diffusion bonding also makes it possible to bond materials with different properties, broadening the scope of composite manufacturing. When using composite materials with compatible thermal properties, diffusion bonding is especially appropriate. It is frequently employed in sectors like aerospace, automotive, and energy where the need for strong, lightweight structures is critical. Manufacturers can produce robust and long-lasting composite assemblies with improved mechanical properties and overall performance by utilising the diffusion bonding technique.

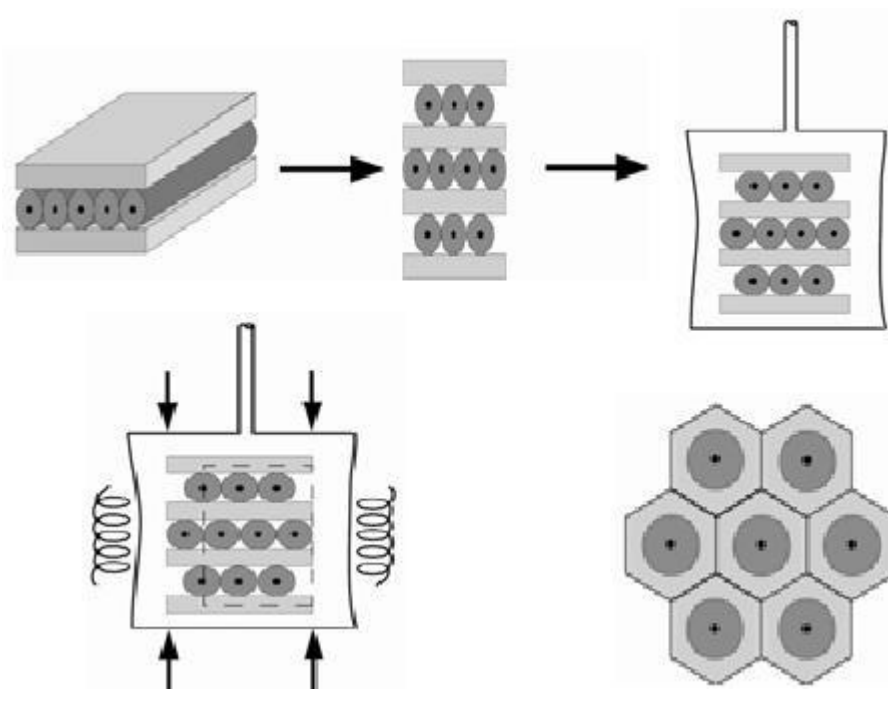


Figure 1.5 Schematic representation of Diffusion bonding casting-[25]

(vi). Centrifugal casting :A very effective technique used in the production of composites is centrifugal casting. This method uses a rotating mould, usually cylindrical in shape, to produce intricate composite parts with superior structural integrity. The preparation of the

composite material, which usually consists of a matrix material reinforced with fibres or particles, is the first step in the process. The composite material is then poured into the mould, and as it quickly spins, centrifugal force spreads the material evenly across the interior of the mould. This force also aids in the removal of air bubbles and voids, producing a dense and uniform composite structure. The mould is stopped and the finished component is removed once the composite material has solidified. The ability to create components with complex shapes, improved fibre orientation, improved mechanical properties, and decreased porosity are just a few benefits of centrifugal casting. When high-performance composite parts are necessary, it is widely used in sectors like aerospace, automotive, and energy.

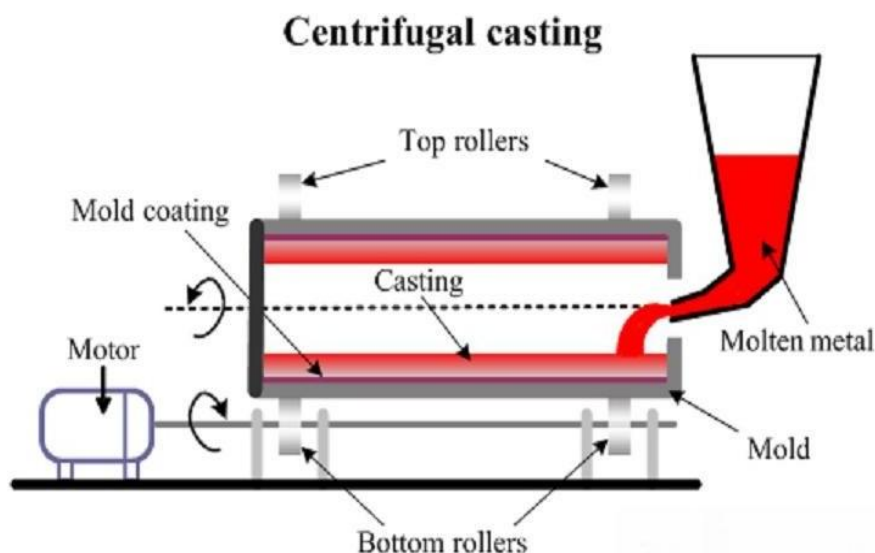


Figure 1.6 Schematic representation of Centrifugal casting-[26]

(vii). Gas pressure infiltration : A common method used in composite manufacturing for producing high-performance and structurally sound components is gas pressure infiltration casting. Under the influence of pressurised gas, molten metal or alloy is infused into a preformed fibrous or porous reinforcement material using this technique. The preparation of a preform made of fibres, such as carbon or glass, arranged in the desired orientation marks

the start of the process. The molten metal is then poured into the mould cavity while the preform is still inside the mould. A controlled amount of gas pressure is simultaneously applied, forcing the molten metal to completely impregnate the preform. The bond between the reinforcing fibres and the solidifying molten metal creates a composite structure with improved mechanical properties. Gas pressure infiltration casting is a preferred method for producing high-performance composite components in a variety of industries due to its benefits, which include improved fibre wetting, decreased porosity, and increased part complexity capabilities.

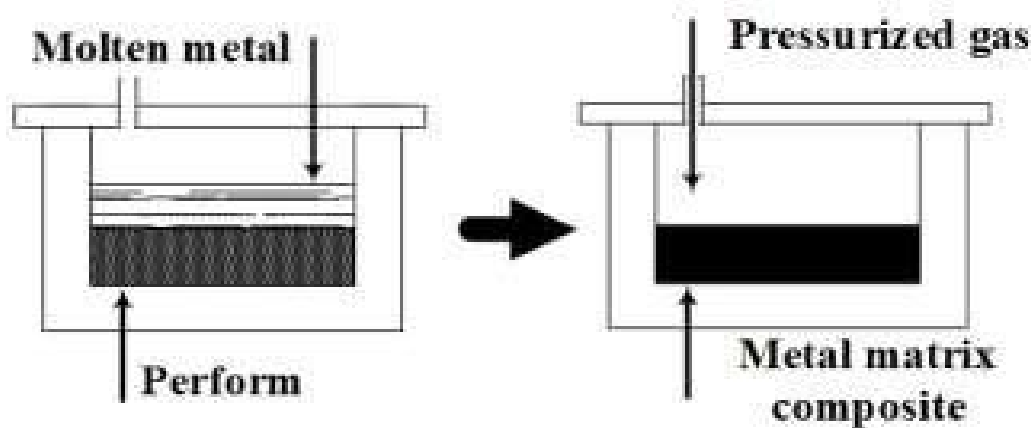


Figure 1.7 Schematic representation of Gas pressure infiltration casting-[27]

CHAPTER 2

LITERATURE REVIEW

According to A. Apasi's, et al (2012) [1] research, the cast composites have substantially smaller grainsizes than the matrix alloy because the matrix alloy contains coconut shell ash particles. With an increasing percentage of added coconut shell ash particle, the produced composites' hardness values rose. For the Al-Si-Fe alloy and composites containing CSA, the coefficient of friction rises with increasing stress. At lower loads, oxidation was the documented wear mechanism, while at greater loads, adhesion and delamination. At lower loads, oxidation was the documented wear mechanism, while at greater loads, adhesion and delamination. It has been found that the wear rate increases along with the applied load. This is due to the fact that as the applied load increases, so does the friction between the material and rotating disc at the contact surface. The Al-Si-Fe alloy matrix is reinforced by adding coconut shell particles to boost the material's wear resistance.

Rajeshkumar Gangaram Bhandare's, et al (2013) [2] studies aim to investigate the various stir casting process operating parameters. Furthermore, to prepare AMC using the stir casting procedure. For this, SiC, Alumina, and Graphite serve as reinforcement, with Aluminium (6061) chosen as the matrix phase. They were able to create AMC successfully and affordably with the use of the stir casting method. We discover that process parameters play a significant impact in the uniform distribution of reinforcement while making AMC. They came to the conclusion that there should be four blades and a blade angle of 45 or 60 degrees for consistent material distribution. They must maintain working temperature at semisolid stage, or 630 for Al (6061), in order to maintain acceptable wettability. It is challenging to distribute the reinforcement in the molten metal in a homogeneous manner when it is fully liquid. Mould preheating improves mechanical characteristics while also lowering porosity.

According to Oluyemi Ojo Daramola, et al (2015) [3], the density of the alloy reduces as the amount of coconut shell in it rises. a sign that composites with lighter components can be made. By using the stir casting technique, composites made of aluminium alloy and coconut shell ash were successfully created. They conducted a microstructural analysis, which reveals the uneven distribution of coconut shell ash particles in the matrix of the aluminium alloy. The smaller levels of porosity in the composites were caused by the interfacial connection between the alloy and the coconut shell ash particles. Aluminium composites with improved hardness and tensile strength can be produced at a low cost by including coconut shell particles into the aluminium matrix. They also examined the composite with a 3.5 wt% NaCl solution and found that the resistance to corrosion decreased as the amount of coconut shell ash particles increased, with the composite containing 12 wt% CSA demonstrating the best corrosion resistance. Comparing 3.5% NaCl solution to 3.0M H₂SO₄ solution, the composites were generally a little more prone to corrosion.

Anand Pai, et al (2015) [4] studied the mechanical properties of five different compositions of hybrid Al 6061-T6 composites reinforced with granite dust and graphite fine particulates. He carried out two-body wear tests on these compositions to come out with the best composition that excels in tribological performance. Al 6061 hybrid composites have been successfully produced by liquid stir casting method and solution heat treatment at 560°C, followed by artificial aging at 180°C for 4- 5 hours given to improve the hardness and strength of the fabricated composites. He found that the wear resistance was significantly increased by adding graphite along with granite dust to Al6061 alloy and heat treating the composites by precipitation hardening. From the wear studies, Granite dust, being economical and available readily, shows good promise as potential ceramic filler and an able substitute to expensive fillers like B₄C, SiC.. Graphite addition is necessary to improve the lubricity at the wear interface and hence hybrid composites of Al alloy (Al6061-T6 in this case) with graphite and granite dust particulates are better equipped for tribological applications.

Premshankar Sahu, et al (2017) [5] investigated the impact of various reinforcements on the mechanical characteristics of composites made of aluminium and metal. He discovered that the choice of reinforcing materials has a significant impact on the overall performance of composites. Metal matrix composites (MMCs) can replace materials like cast iron and steel in applications such as aerospace, automotive, and other industries thanks to their appealing physical and mechanical characteristics. Due to their combination of qualities, AMCs are promising materials that can be improved even more by adding suitable reinforcing materials to the base metal during the casting process. Aluminium oxide (Al_2O_3) in the form of particles or whiskers and silicon carbide (SiC) are two frequently used reinforcements for AMCs. The processing method, the size of the reinforcement, and the weight fraction all have an impact on the mechanical characteristics of AMCs. Ceramic-reinforced AMCs are thought of as new-generation materials that can be tailored and engineered for better properties. The ability of AMCs to be economically viable for various applications is essential to their successful commercial production.

According to T. Nithyanandhan's, et al (2017) [6] research, stir casting was used to fabricate an aluminium-based MMC reinforced with B4C particles and a hybrid composite made of coconut shell ash. The hardness, tensile test, and microstructure of the fabricated MMC were also assessed in light of the working conditions. The mechanical behaviour of a hybrid aluminium-metal composite that contains varying amounts of B4C and coconut shell ash as reinforcement has been studied. The outcome reveals that when compared to aluminium 6061, the hybrid composite's hardness slightly decreased. Through comparing the hybrid composite's tensile strength to that of aluminium 6061, It was found that the hybrid composition's fracture toughness was higher than that of the single- reinforced aluminium 6061.

Balasubramani Subramaniam, et al (2018) [7] conducted research on the hybrid aluminium matrix composites' (HAMC) mechanical characteristics. Al7075, an aluminium alloy, was strengthened with boron carbide (B4C) and coconut shell flour ash (CSFA) particles. Stir casting

was used to create composite materials made of an Al7075 matrix. He discovered that the microstructure results demonstrate consistent reinforcement distribution and a low level of porosity in the composites. Because of the higher mechanical properties displayed by the hybrid composites produced, the production of low-cost hybrid aluminium matrix composites using coconut shell fly ash as a complementary reinforcement with boron carbide has a significant advantage. He also observed that the reinforcement content in the matrix increases with composite hardness.

The composite with 12 weight percent B4C and 3 weight percent CSFA exhibits the highest hardness (169.5 BHN) of all composites. By incorporating reinforcement particles B4C and CSFA into the aluminium 7075, composites' tensile strength is increased. The 9-weight percent B4C and 3-weight percent CSFA composite achieves the highest tensile strength (189 MPa), a 66% improvement over unreinforced aluminium 7075. With an increase in the weight percentage of reinforcement particles, the ductility of the composites declines. He observed that the dimple formation in the composites is visible on the fracture surface of tensile test specimens. There is less porosity and better interface bonding as a result of the multiple reinforcements.

Arun Kumar Sharma, et al (2020) [8] conducted research on the stir casting process used in the fabrication of composites based on aluminium. He found that there has been a rising interest in composite materials as a result of the increased demand for affordable products that don't sacrifice quality in recent years. The term "composite material" refers to a mixture of two or more materials that have distinct phases and have better properties than the base material. MMCs are frequently acknowledged as a potential material for many industrial applications due to ongoing advancements. Aluminium metal matrix composites are attracting a lot of attention among MMCs because of their superior mechanical characteristics, light weight, and affordable price. MMC materials can be produced using a variety of techniques, and AlMMCs can also be produced using a variety of methods. Even with the same composition and quantity of materials, distinct characteristic profiles can be achieved by changing the fabrication process and

incorporating different reinforcement materials. This article discusses various factors that generally affect the fabrication process in addition to giving a brief overview of the liquid fabrication process with a focus on the stir casting technique.

Hammar Ilham Akba, et al (2020) [9] emphasises low-cost manufacturing and environmentally friendly practises in this essay as he focuses on the sustainable development of materials. Al₂O₃, SiC, and graphite are just a few of the chemically produced reinforcements that the researchers plan to incorporate into their lightweight metal matrix composites. Improvements in the materials' mechanical, physical, thermal, and corrosion properties can be seen thanks to these reinforcements. The paper emphasises the possibility of using alternative reinforcing materials that are affordable, accessible, and have physical and mechanical properties similar to traditional particulates. Waste products from industry and agriculture that are high in oxide content are identified as potential replacements for metal matrix composites. According to the literature review, some examples of these waste materials include fly ash, bottom ash, rice husk ash, and bean pod ash, which have all been used as reinforcements in metal matrix composites. It has been claimed that adding particulates made from agricultural and industrial waste has improved the mechanical properties of composite materials. This suggests that using these waste materials as reinforcements may have positive effects on material performance in addition to helping to promote sustainable practises.

N. Ramadoss, et al (2020) [10] conducted research on a hybrid composite made of B₄C and BN-reinforced Al7075 hybrid composites. B₄C and BN-reinforced Al7075 hybrid composites are made using the stir casting technique. In this study, the researchers used the stir casting method to make hybrid composites of Al7075 reinforced with B₄C and BN. B₄C weight percentages varied (3%, 6%, and 9%), whereas BN weight percentage was maintained at 3%. Marine applications were the intended use for the composites. Optical microscopy was used to analyse the morphology of the synthesised aluminium hybrid composite, and the results showed that the reinforcement particles were evenly distributed throughout the base metal matrix. Al₃BC,

AlB₁₂, and AlN were also produced as a result of interfacial reactions. To assess the hardness of the hybrid composites, Vickers micro-hardness testing was done. When compared to the Al7075 base matrix alloy, it was found that the hardness of the composites increased as the percentage of reinforcement increased. Cast composite specimens with various compositions underwent mechanical testing. According to the findings, adding B₄C and BN reinforcement increased the hybrid composites' strength by 22%. The inclusion of harder reinforcements improved the resistance to applied loads, thereby enhancing the compression properties of the composites, according to an evaluation of the hybrid composites' compressive properties using the ASTM E9 standard. Using ASTM-B117, the corrosion behaviour of the hybrid composites was investigated. With the addition of 3% to 6% boron carbide, it was found that the corrosion rate decreased by 18.5%, and with the addition of 6% to 9% boron carbide, it decreased even more, by 22.4%. Overall, the research showed that the synthesis of B₄C and BN-reinforced Al7075 hybrid composites enhanced their mechanical, hardness, and corrosion resistance, making them suitable for marine applications.

Adekunle Adetayo Yekinni, et al (2020) [11] investigated how the properties of an aluminium matrix strengthened with graphite and CSA increased. He used stir casting to successfully create a hybrid composite from recycled aluminium cans, adding reinforcement made of graphite and CSA with a 150-m particle size. The composites' micrographs revealed that the CSA and graphite particles were distributed fairly uniformly throughout the matrix of aluminium alloy. Porosity is minimal, and shrinkage-related casting flaws did not show up. When the composite was reinforced with 2 wt% graphite and 8 wt% CSA, a noticeable increase in hardness from 220.9 HV to 285.7 HV was obtained, representing a total increase of about 70%.

Because of the additives' innate properties, it was discovered that the impact energy and density of the composites both showed a decreasing trend in the final product.

The composites made from recycled aluminium cans and strengthened with graphite and coconut shell ash are suitable as potential materials for the manufacture of the majority of

standard automobile components.

Rohit Chandel, et al (2021) [12] investigated the stable, uniformly distributed microstructures of hybrid composites made at various weight percentages of reinforcement particles. They discovered that stir casting and the powder metallurgy procedure are the most often employed processes for the creation of hybrid composites. Hard reinforcement particles can be added to hybrid composites to strengthen them even more. The mechanical properties of these composites were found to be greatly enhanced by the addition of ceramic particles such as silicon carbide (SiC), aluminium nitride (AlN), alumina (Al₂O₃), and boroncarbide (B₄C). Graphite (Gr), a solid lubricant, has a lot of potential to be used as supplementary reinforcement for materials with outstanding mechanical and wear qualities. The agricultural waste derivatives, such as fly ash (FA), ricehusk ash (RHA), and coconut shell ash (CSA), have the potential to replace the secondary reinforcement in the next generation of hybrid composites.

Bisma Parveez (2021) [13] studied various agro-based reinforcements and their influence on the microstructural, mechanical, and tribological properties and the processing techniques involved. Some of the key findings made by them are the addition of various combinations of reinforcements in the composites are developed to attain desirable mechanical properties that are difficult to achieve in ceramic reinforced composites. The agro-based AMC's reinforced with agro waste products have revealed that the better performance of AMC's can be reached at lower production cost even though replacement of about 50% synthetic reinforcement by the agrowaste is possible without compromising any property. They found that replacing SiC or alumina by the agro-waste in small quantity results in an improvement in properties of the composite. The agro-based reinforcements like, maize stalk ash, coconut shell ash, rice husk ash, etc. reduce the density of AMC's on their addition to composites. However, acceptable porosity levels are obtained in these composites. They found that mechanical properties of agro-based AMC's revealed that the mechanical properties can be controlled by varying composition and reinforcements. Various research works include agro-based materials as reinforcements and

have studied influence, characteristics and properties of the AMC's; however, these also depend on the production technique employed. They noticed Among all the techniques stircasting has been used extensively, however, it has various limitations associated, such as wettability and nonuniform dispersion of reinforcements. Thus, other techniques are now considered such as friction stir casting and powder metallurgy. These agro-waste materials have the potential to replace the hazardous reinforcements such as asbestos fiber used as a friction material in automobiles; coir fiber, when reinforced in the aluminum composite, has proved to be better candidate material as filler materials in brake pad applications and thus expand their scope of applications.

Hemanth Kumar K.S, et al (2021) [14] investigates how matrix material is influenced by reinforcement materials like coconut shell ash. Coconut Shell Ash and TiO₂ particles have been successfully used as reinforcement elements in stir casting to create composites with aluminium 6061 as the matrix material. When compared to an unreinforced alloy, the average grain size decreases in the presence of coconut shell ash and TiO₂ content in the matrix. The hybrid composites show a significant degree of grain refinement. As the blend's TiO₂ and Coconut Shell Ash concentrations are raised, the composite becomes harder. Because the TiO₂ particles in the samples serve as elements of load bearing, adding reinforcement will also make the composites harder.

Bharat Singh, et al (2023) [15] investigated the AMMCs' mechanical and microstructural characteristics. With reference to the applications, the effects and significance of the various reinforcing materials on the final composite are given and addressed. The study disseminates and advances knowledge regarding various mechanisms for strengthening, interfacial bonding, hardness, and ultimate strength of synthetic composite. Various factors, including production costs, product quality, and the intended use of the product, are taken into account when choosing where to apply different reinforcing elements.

By strengthening the self-lubricating components like graphene, carbon nanotubes (CNT),

multiwalled carbon nanotubes, etc., wear resistance in AMMCs can be increased. Better kinetics at the interfaces are offered by the powder metallurgy approach for the manufacturing of AMMCs. By using quick solidification of tiny powders, the structure is refined more effectively. Furthermore, it aids in preventing the aggregation of reinforcing elements. They discovered that the stir casting procedure for AMMCs is effective and yields a product with a net shape. However, its use in nano metal matrix composites is constrained by the aggregation of reinforcing nanoparticles. Additionally, it was discovered that the parameters of the fabrication process, the type of reinforcing elements, and the reaction at the interface have a significant impact on the microstructure of the final composite. By virtue of grain refinement strengthening, heterogeneous nucleation of grains brought on by the presence of reinforcing materials increases the strength and hardness of the composite (Hall Patch equation). The strength, hardness, and structural integrity of nano reinforce composites are superior to those of micro and macro reinforce composites.

CHAPTER 3

MATRIX AND REINFORCEMENT MATERIALS USED FOR COMPOSITE MANUFACTURING

3.1 ALUMINIUM WIRE REINFORCED WITH CSA AND B₄C

An innovative composite material, aluminium wire reinforced with coconut shell ash and B₄C (boron carbide), combines the strength and light weight of aluminium with the improved performance properties offered by the addition of coconut shell ash and B₄C particles. Coconut shell ash, which is made from leftover coconut shells, is a natural and environmentally friendly material with many advantages, including low density, high porosity, and effective thermal insulation. It improves the composite's overall mechanical strength and resistance to wear when combined with aluminium.

The high-performance ceramic B₄C is included to fortify the aluminium wire composite even more. B₄C is a well-known material due to its exceptional hardness, low density, and outstanding resistance to abrasive wear. By adding B₄C particles, the composite material becomes tougher, stiffer, and more resistant to corrosion and deformation. In terms of mechanical properties and performance, a composite made of B₄C and coconut shell ash performs better than pure aluminium wire.

The light weight of aluminium wire reinforced with coconut shell ash and B₄C is one of its main benefits. Since aluminium is known for having a low density, it is a popular material for applications where weight reduction is important. This property is further improved by the addition of coconut shell ash and B₄C, enabling the creation of lightweight components and structures without sacrificing strength and durability. Applications for this composite material

can be found in the construction, automotive, and aerospace sectors, where weight reduction can improve overall performance and fuel efficiency.

The addition of coconut shell ash to the composite also benefits the environment. Coconut shells are a plentiful source of waste, and using them in composites helps cut down on landfill waste and promote sustainability. The composite gains desirable mechanical properties by incorporating these agricultural waste products, and it also supports the circular economy and lessens reliance on non-renewable resources.

Aluminium wire reinforced with coconut shell ash and B_4C is a promising composite material that combines the advantages of coconut shell ash and B_4C with the lightweight and strength of aluminium. The composite is ideal for a variety of applications because it has excellent mechanical strength, wear resistance, and corrosion resistance. This composite has a lot of potential for industries looking for effective and environmentally friendly solutions because of its lightweight design and sustainable sourcing.

3.1.1 Properties of Constituent Phases

(i). Matrix material -Aluminium

In my research, aluminium extracted from used wire was utilized. Due to its exceptional combination of characteristics, aluminium metal is frequently used as a matrix material in composites. Aluminium is a great material for lightweight applications where strength is important since it has a great strength-to-weight ratio. Due to its low density, it can be significantly lighter, increasing both payload capacity and fuel efficiency. The strong corrosion resistance of aluminium further enables the composite material to withstand challenging environmental conditions and increase service life. Additionally, aluminium has strong electrical and thermal conductivity, making it appropriate for uses that need for effective electrical or heat transmission. Its malleability and formability make it simple to shape and fabricate, which

makes it possible to create intricate composite structures. Overall, aluminum's adaptable qualities make it a highly sought-after matrix material for composites, permitting the development of novel and highly effective products across numerous industries.

(ii). Reinforcement material – Coconut Shell Ash

Because of its distinct qualities and widespread availability, coconut shell ash is frequently used as a reinforcing material in composites. First off, coconut shell ash is an environmentally favourable solution for composite reinforcement because it is a natural byproduct of the coconut industry. This environmentally friendly feature fits perfectly with the rising demand for eco-friendly products. Additionally, the high strength, stiffness, and hardness of coconut shell ash provide great mechanical qualities that increase the composite material's overall durability and strength. It also demonstrates strong thermal stability, making it appropriate for uses involving high temperatures. Additionally, the low density of coconut shell ash contributes to the composites' small weight, making them perfect for applications that call for weight reduction without sacrificing strength. Coconut shell ash is an attractive option for reinforcing composites in a variety of industries, including automotive, aerospace, and construction, due to its affordability and abundance.

(iii). Reinforcement material – B_4C

The versatile material boron carbide (B_4C) is widely used as a reinforcement in composite materials. Composites are engineered materials made of two or more different parts that work together to improve the material's overall mechanical and physical properties. Typically, a matrix material and reinforcing elements make up a composite.

Due to its exceptional stiffness, strength, and hardness, B_4C makes an excellent reinforcement material for composites. It is one of the hardest substances ever discovered, second only to

diamond, making it extremely durable and abrasion-resistant. This property enables composites reinforced with B₄C to withstand challenging conditions and extended use without noticeably degrading.

To improve the mechanical properties of composite materials, B₄C is typically incorporated into a matrix material like polymers, metals, or ceramics. The matrix is strengthened by the B₄C particles, increasing its strength, stiffness, and impact resistance. This reinforcement effect contributes to increased structural integrity by reducing the likelihood of crack propagation and enhancing load-bearing capacity.

Additionally, B₄C-reinforced composites have excellent thermal stability and high temperature resistance, making them suitable for use in the aerospace, defence, automotive, and sporting goods industries. Due to B₄C's high melting point, composite materials can maintain their mechanical properties even at high temperatures, offering thermal protection and structural integrity under difficult circumstances.

B₄C is an excellent reinforcement material for composites because it has high strength, hardness, wear resistance, and thermal stability. B₄C-reinforced composites are the best choice for applications that call for lightweight, strong, and high-performance materials that can withstand harsh environments because of these characteristics.

3.2 PREPARATION OF REINFORCEMENTS

3.2.1 Preparation of CSA

- (i). Collect and clean the coconut shells: Begin by gathering coconut shells from a dependable source. Clean them properly to remove any exterior pollutants, such as dirt or fibres.



Figure 3.1 Collected coconut shell

(ii). Drying the coconut shells: After cleaning, the moisture content must be removed by drying the coconut shells. You can achieve this by putting them somewhere with good ventilation and letting them air dry for a few weeks. As an alternative, you can quicken the drying process by using an oven or a kiln.



Figure 3.2 Cleaned coconut shell

(iii). Burning the coconut shells: To turn the dried coconut shells into ash, they must be burned. They can be heated to a high temperature by being placed in a furnace or kiln. Coconut shells should be burned at a temperature of 400 degrees Celsius for 2 hours.



Figure 3.3 Burning coconut shell on furnace

(iv).Cooling and collecting the ash :After the coconut shells have been burned, let them cool naturally before collecting the ash.



Figure 3.4 Collected coconut shell ash from furnace

(v). Grinding and sieving: Use a pulverizer and sieving machine to crush the collected coconut shell ash into fine, uniform particles (<53 microns). It will be easier to get rid of any bigger contaminants or particles by sieving the ash through a fine mesh.



Figure 3.5 CSA of <53 microns

- (v). Reheating: The structural qualities of coconut shell ash reinforcements are improved by reheating them in a furnace at a temperature of 800 degree celsius for 12 hours.
- (vi). Storage: To avoid moisture absorption and contamination, keep the prepared coconut shell ash in a clean, dry container with a tight lid. The quality and efficiency of the ash as a reinforcement material will be guaranteed by proper storage.

CHAPTER 4

METHODOLOGY

4.1 STIR CASTING METHOD

The advantages of both the casting and stirring processes are combined in the widely used metal casting technique known as stir casting. It entails adding strengthening components, like fibres or particles, to a molten metal matrix. The procedure starts with the base metal being melted in a crucible or furnace, then the necessary reinforcing material is added. A mechanical stirrer is then used to agitate and distribute the reinforcing particles evenly throughout the molten metal after the mixture has been formed. This stirring ensures that the reinforcements are distributed evenly and prevents settling or agglomeration. The molten metal is cast into a mould to solidify and create the finished component after the stirring process. Stir casting is advantageous for a variety of applications, particularly in the automotive, aerospace, and manufacturing industries. These uses include greater mechanical characteristics, improved thermal conductivity, and increased wear resistance.

4.1.1 Steps in casting process of aluminium composite

(i). Material Preparation:

- Melt the metal matrix (aluminium wire) in a crucible or furnace to prepare it. Maintain the temperature at the melting point of the particular material. If necessary, pre-treat the reinforcing material to guarantee good adhesion to the matrix. Techniques for surface treatment or coating could be used here.
- The operation is performed at 800 degrees Celsius.

(ii). Mixing and Degassing:

- Add the CSA and B₄C reinforcing material to the molten metal matrix.
- Use an impeller or mechanical stirrer to agitate the mixture. The agitation of the molten metal helps distribute the reinforcing material uniformly.
- Degas the molten metal simultaneously to get rid of any trapped gases or impurities. Applying a hoover or using a proper degassing chemical can do this.

(iii). Mould preparation

- To prevent rapid cooling and improve material flow, preheat the mould to a sufficient temperature.
- Use a mould release agent or coating to make it easier to afterwards remove the casting.

(iv). Casting:

- Fill the mould with the molten metal-reinforcement mixture.
- To guarantee that the reinforcing material is distributed uniformly, keep the pouring rate under control and steer clear of turbulence.
- Permit the casting to harden inside the mould as it cools. The resulting microstructure and MMC's physical characteristics can be influenced by the cooling rate.

(v). Post-Casting Operations:

- After the casting has set, take it out of the mould.
- Carry out any required auxiliary procedures, such as surface finishing, machining, or trimming extra material.
- Make that the desired dimensions, surface finish, and mechanical qualities are met by conducting inspections and quality checks.

4.1.2 Merits of stir casting

- Enhanced mechanical properties
- Tailored properties
- Cost effectiveness
- Good thermal properties
- Better wear properties
- Good machinability
- Design flexibility

4.2 SPECIMEN EXTRACTION USING WIRE CUT EDM PROCESS

Using conductive materials, complicated designs can be carved using the precision machining technique known as EDM (Electrical Discharge Machining). A thin, electrically charged wire, often composed of brass or copper, is used in this process and is steered through the workpiece under precisely regulated circumstances. Wire cut EDM is an EDM technique that uses a succession of quick electrical discharges to erode the material and produce the desired form.

Here, the wire-based tooling is made to move along the X, Y, and Z axes under the control of a CNC controller. For procedures involving precision machining and contour machining, wire cut EDM is typically recommended.



Figure 4.1 Cutting tool and specimen



Figure 4.2 CNC unit

4.2.1 Advantages of wire cut EDM method

- Precision
- Minimal Workpiece Contamination
- Versatility
- Minimal Material Stress
- No Tool Contact
- Complex Shapes and Small Holes
- Automation and Unattended Operation

4.2.2 Specimen for impact test

In many different industries, ASTM standards are essential for maintaining the high quality and dependability of materials and products. The ASTM E23 standard is frequently used when impact testing, specifically on a Charpy machine. This standard offers instructions for performing notch toughness tests to evaluate the impact resistance of metallic materials. The size and preparation of the test specimens, as well as the kind and placement of the notch, are specified. The ASTM E23 standard also describes how to conduct the test, which entails striking the specimen with a pendulum hammer and calculating the energy lost during fracture. Manufacturers and researchers can test the impact properties of materials efficiently and produce results that are similar and accurate by following this standard, allowing them to decide on the performance and suitability of the material for different applications.

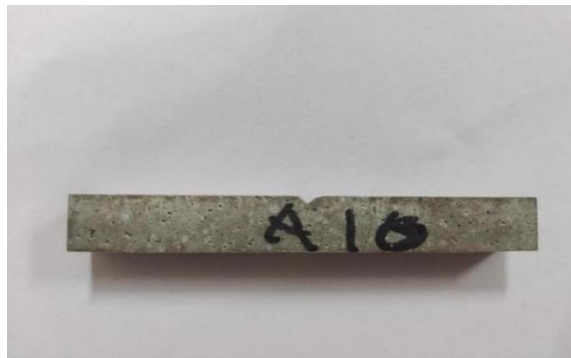


Figure 4.3 Specimen for impact testing (Side view)



Figure 4.4 Specimen for impact testing (Top view)

Table 4.1 Specifications of impact specimen

Length	55 mm
Width	10 mm
Notch angle	45degree
Notch depth	2mm

CHAPTER 5

TESTING AND ANALYSIS

5.1 DENSITY MEASUREMENT

To determine the density of a recently manufactured composite, follow these steps: First, obtain a small, solid sample of the composite material to ensure that it is a true representation of the entire composite. The sample's mass should then be precisely determined using a precise balance or scale. The mass should be converted to grams (g). determine the sample's volume next. If the composite has a consistent shape, such as a cube or cylinder, measure its dimensions and calculate the volume appropriately using a ruler or calliper. Use the displacement method if the composite has an irregular shape. Carefully submerge the sample in a graduated cylinder of water that has been filled to the proper level, then measure the volume that changes. To determine the density, divide the sample's mass by its volume. It will be possible to measure density in grammes per cubic centimetre (g/cm^3) or another comparable unit. A sample that is 1 cm^3 in size is cut, and its mass is calculated.

$$\text{Density} = \text{Mass}/\text{Volume}$$

5.2 GRAIN SIZE MEASUREMENT AND POROSITY DISTRIBUTION

The optical microscope is a flexible tool that is frequently used in many academic fields for the analysis of porosity distribution and grain size measurement. It allows researchers and scientists to closely examine the microstructure of materials because it can deliver high-resolution imaging.

In material science and metallurgy, grain size measurement is a crucial variable. The size of each grain in a sample can be seen and measured by researchers using an optical microscope. They can evaluate the material's general microstructural properties as well as the distribution of

the material's grain sizes and boundaries. Given that grain size can have a significant impact on a material's mechanical, thermal, and electrical properties, this knowledge is essential.

The analysis of the porosity distribution is another crucial application of optical microscopy. A material's porosity is defined as its presence of void spaces. The strength, resilience, and other properties of the material may be impacted by these voids. Researchers can locate and quantify the location and morphology of pores within a material by using an optical microscope. Insights into the material's permeability, density, and structural integrity can be gained by analysing variables like pore size, shape, connectivity, and spatial arrangement. Researchers typically prepare thin sections or polished surfaces of the material under study for the optical microscope experiments that measure grain size and analyse porosity distribution.

They then use different imaging methods to improve the contrast and visibility of the grains or pores, such as brightfield, darkfield, or polarised light microscopy. Researchers can obtain detailed images and measure the dimensions of individual grains or pores using calibrated scales or software-based image analysis tools by choosing the appropriate magnification levels.

There are several benefits to using optical microscopy to measure grain size and analyse porosity distribution. Repeated measurements can be made on the same sample using this non-destructive method, facilitating statistical analysis and the assessment of sample variability. Optical microscopy is also more affordable and swift than other cutting-edge imaging methods.

Additionally, it provides visual information that aids in the interpretation and understanding of microstructural features by other analytical methods like electron microscopy or X-ray imaging. The optical microscope is an essential tool for analysing the distribution of porosity and measuring grain size. Its ability to deliver high-resolution imaging and quantitative data enables researchers to examine the microstructure of materials, assess their properties, and gain insights into their behaviour and performance.



Figure 5.1 Optical microscope

5.3 ROCKWELL HARDNESS TESTING DEVICE

In the field of material science and engineering, the determination of a material's resistance to indentation or deformation is accomplished through the hardness testing procedure. The Rockwell hardness test, which makes use of a Rockwell hardness testing device, is one frequently used technique. In order to calculate the material's hardness value, this machine applies a minor initial load followed by a major load to a particular area of the material's surface. The ASTM E18 standard, which outlines the process, is followed by the Rockwell hardness testing machine. Depending on the material being tested, the standard specifies the test forces, indenter types, and corresponding scales to be used. A dial or digital display for reading the hardness value, a variety of indenter options, such as diamond or steel balls, and a vertical load application system are the typical components of the machine.

Specific specimen preparations are needed for Rockwell hardness testing in accordance with the ASTM E18 standard. In order to guarantee precise and consistent results, the standard specifies the specimen's dimensions, surface finish, and minimum thickness. The standard also offers instructions for the specimen's positioning and alignment inside the apparatus, ensuring proper contact between the indenter and the surface. Following these ASTM guidelines ensures consistent and reliable hardness values for various materials and applications.



Figure 5.2 Rockwell hardness testing device

Table 5.1 Specifications of Rockwell hardness testing device

Parameters	Specifications
Intender	Ball
Scale	B scale
Major load	90 kg
Minor load	10 kg

5.4 CHARPY IMPACT TESTING MACHINE

The Charpy impact testing machine must have particular features and abilities in order to conduct impact tests on an aluminium composite specimen in compliance with ASTM E23 standard. First, the machine needs to be able to handle the standard specimen size, which is normally a rectangle with a cross-section of 55 mm x 10 mm. A suitable pendulum hammer with enough energy to provide the requisite impact force should also be included in the machine.

Impact testing requires accuracy and precision, hence the Charpy machine should have an accurate and calibrated measurement system. This frequently incorporates a reliable strain gauge or load cell that precisely records the force generated during the collision. To record and preserve the findings of the impact test, the equipment should also have an effective data gathering system. The machine must also provide customizable settings so that it may handle various test requirements. For optimal alignment with the specimen and constant test circumstances, this also offers the option to modify the height and placement of the striker and anvil. Because some materials may behave differently depending on the temperature, the machine should also be able to control the test temperature. In every impact testing device, safety features are crucial. Safety features for the Charpy machine should be included to safeguard users and avoid equipment damage. To ensure secure functioning while being tested, this may incorporate safety guards, interlocks, and emergency stop features. Overall, the Charpy impact testing apparatus should include the capacity, accuracy, precision, adaptability, and safety characteristics required for impact tests on aluminium composite specimens that are compliant with ASTM E23, in order to guarantee consistent and dependable test results.



Figure 5.3 Charpy impact testing machine

5.5 CORROSION TESTING APPARATUS

The electrochemical corrosion testing method was used to determine the rate of corrosion of aluminium alloy and aluminium composite in seawater. The useful method of electrochemical corrosion testing, which offers essential information on the materials' corrosion behaviour, Numerous parameters, including impedance value, open circuit potential, corrosion rate, and corrosion current, are measured during this testing. The impedance value, a measurement of the resistance to the flow of electric current, sheds light on the surface's protective properties. The voltage difference between a material that is corroding and a reference electrode is known as the "open circuit potential," and it represents the thermodynamic propensity for corrosion to occur. Corrosion rate measures how quickly a material corrodes and is expressed in mass loss per unit area per time. On the other hand, corrosion current is a representation of the flow of electrons during the corrosion process. Engineers and researchers can evaluate the efficiency of corrosion protection techniques, gauge the performance of materials, and create plans to lessen corrosion-

related damage by analysing these parameters through electrochemical corrosion testing.

(i). Corrosion Analysis:

- As the corrosion rate calculation will be based on seawater conditions, a 3.5 wt% NaCl solution is made, representing the percentage composition of seawater.
- Immersion of Specimen: To start the corrosion process, the prepared specimen, counter electrode, and reference electrode are all dipped into the NaCl solution. In this arrangement, the specimen functions as the working electrode, a platinum wire acts as the counter electrode, and HgCl, also known as a calomel electrode, acts as the reference electrode.
- Runtime: The corrosion analysis process runs for a predetermined amount of time, usually 500 seconds, giving corrosion enough time to take place.
- Result Recording: A computer connected to the corrosion analysis instrument automatically records and collects all corrosion-related data and measurements.



Figure 5.4 Corrosion testing apparatus

(ii). Prepare the specimens:

- Surface Preparation: The specimens are ready by using emery paper of various grades to polish their surfaces. This guarantees a smooth and uniform surface for precise corrosion analysis.

- **Beeswax Coating:** Beeswax is applied to the entire specimen's surface, with the exception of a designated 1 cm² area that will experience corrosion. The coated areas are shielded from corrosion by this protective coating.



Fig 5.5 Corrosion test specimen

(iii).Circuit Setup:

- **Connection to Wire:** The specimen is connected to a wire, which is a necessary part of setting up the corrosion analysis circuit.
- **Corrosion Analysis Circuit:** The wire-connected specimen is submerged in a prepared 3.5 wt% NaCl solution along with a counter electrode and a reference electrode. The electrodes are connected to a corrosion analyzer or an electrochemical analyzer to complete the circuit.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 DENSITY MEASUREMENT RESULT

Table 6.1 Density values

Material	Density (g cm ⁻³)
Aluminium alloy	2.69
Aluminium composite	2.59

- When switching from aluminium alloy to composite material, the density decreases by 3.7%. In a variety of applications, reducing the density of aluminium composites can provide several benefits.
- The composite has a density of 2.59 g/cm³, while the aluminium 1350 alloy has a density of 2.69 g/cm³. This suggests that the aluminium 1350 alloy is heavier than the composite material.
- The composite material will weigh less per unit of volume than the aluminium 1350 alloy because of its lower density. In applications where weight reduction is desired, like the aerospace or automotive industries, this may be advantageous.
- The advantages of lightweight composites' low weight can be found in the aerospace, automotive, and transportation sectors. It lowers the amount of energy needed for operation, improving fuel efficiency and lowering carbon emissions. This is especially helpful in today's society, where environmental protection and sustainability are top priorities.

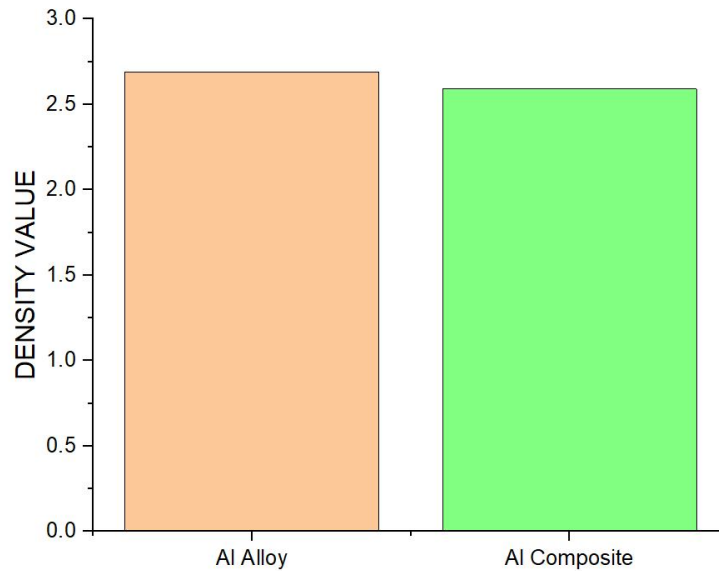


Figure 6.1 Comparative bar chart illustrating the Density analysis result

6.2 GRAIN SIZE MEASUREMENT AND POROSITY DISTRIBUTION RESULT

With an increase in the amount of reinforcement, porosity distribution in composites tends to increase. The main reason for this is that it is harder to evenly wet and disperse the reinforcement material at higher concentrations. The matrix material's viscosity may rise along with the reinforcement content of the composite, making it more difficult for the matrix to penetrate the reinforcement's interstitial spaces. The composite structure may consequently develop isolated areas of porosity.

Porosity in composites can negatively affect their mechanical characteristics, lowering their impact strength, among other things. Reduced load-bearing capacity and increased susceptibility to crack initiation and propagation are the results of porosity acting as stress concentrators. These voids can serve as sites for the initiation and spread of cracks when exposed to impact

loading, decreasing the composite's capacity to absorb energy and impairing its impact resistance. To prevent porosity formation and guarantee the desired mechanical properties, it is crucial to carefully control and optimise the processing parameters and reinforcement content in composite manufacturing. By reducing porosity and boosting impact strength, techniques like proper mixing, degassing, and optimising curing conditions can be used to make composites more suitable for applications requiring high structural integrity and impact resistance.

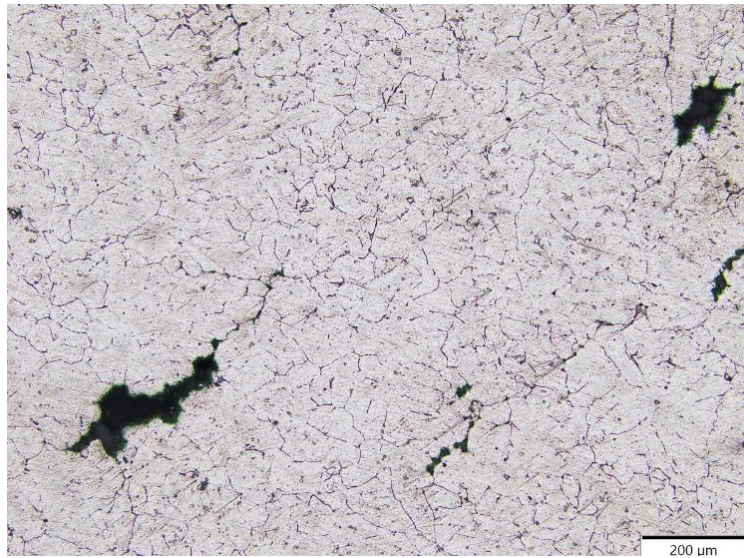


Figure 6.2 Optical image of Al alloy

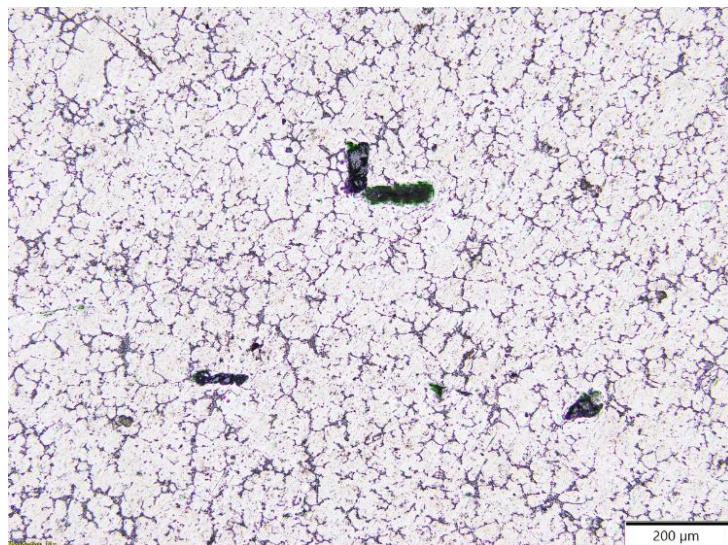


Figure 6.3 Optical image of Al composite

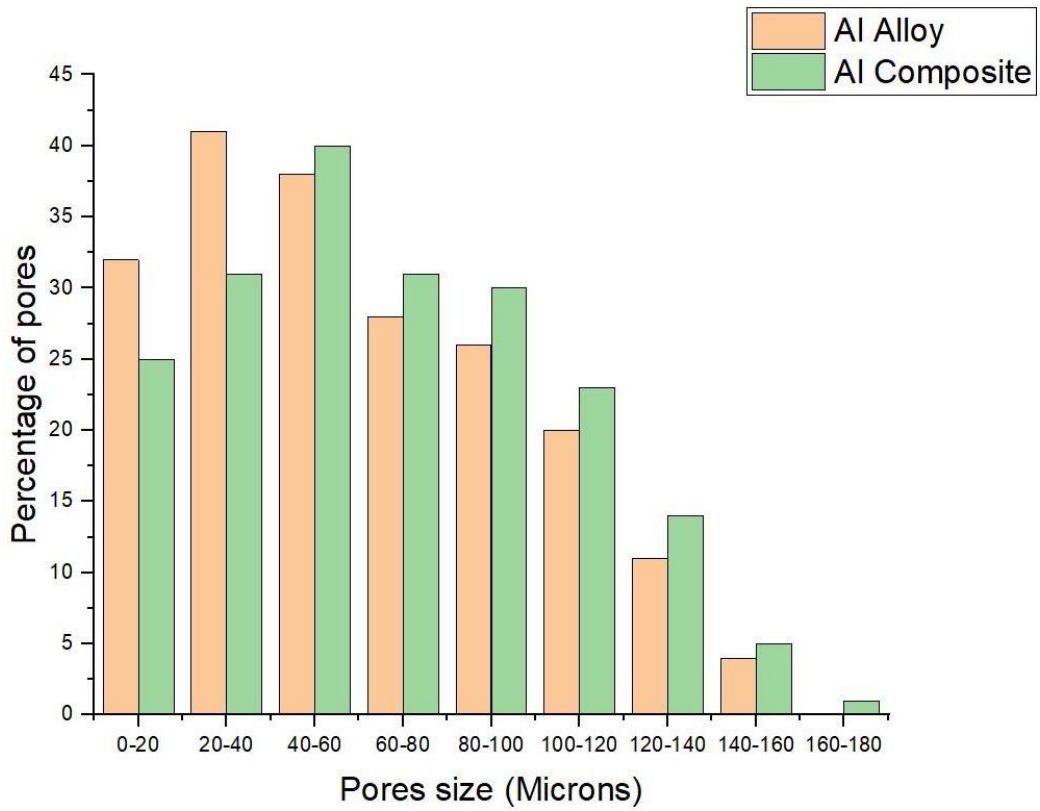


Figure 6.4 Comparative bar chart illustrating the pore size analysis result

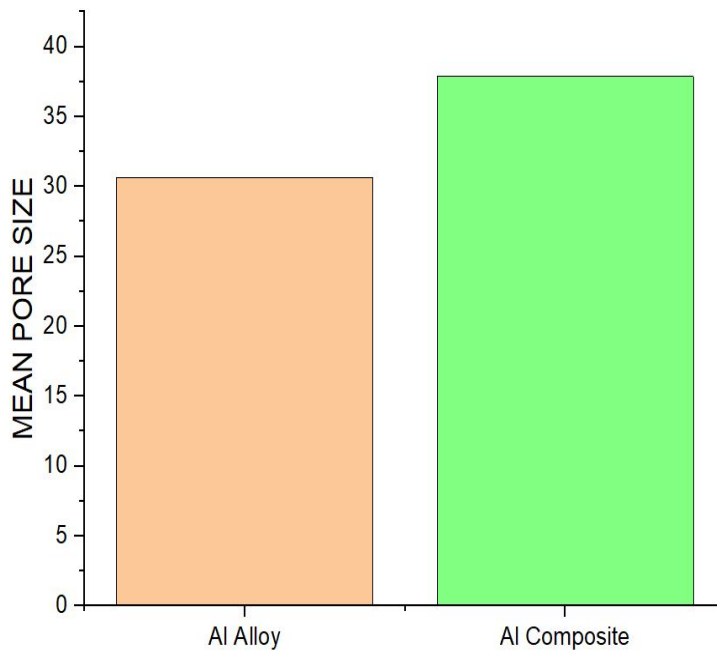


Figure 6.5 Mean pore size analysis result

The grain size of a composite material plays a significant role in determining its mechanical and physical properties. The influence of grain size on a composite can be observed in various aspects. Firstly, the mechanical strength of the composite is greatly affected by the grain size. Generally, smaller grain sizes result in enhanced mechanical properties, including increased strength, hardness, and stiffness. This is due to the smaller grain boundaries, which hinder the propagation of dislocations and improve the load-bearing capacity of the composite. On the other hand, larger grain sizes can lead to reduced strength and increased susceptibility to deformation or failure. Secondly, the grain size has an impact on the composite's toughness and fracture behaviour. Because the grain boundaries act as obstacles to the advancing cracks, smaller grain sizes encourage a higher resistance to crack propagation. This improves the material's ability to withstand fracture. Larger grain sizes, on the other hand, might make it easier for cracks to spread along grain boundaries, resulting in less toughness. In comparison to that aluminium alloy, the microstructure images of the aluminium composite show a smaller grain structure. In comparison to the aluminium alloy, it can therefore contribute better mechanical properties.

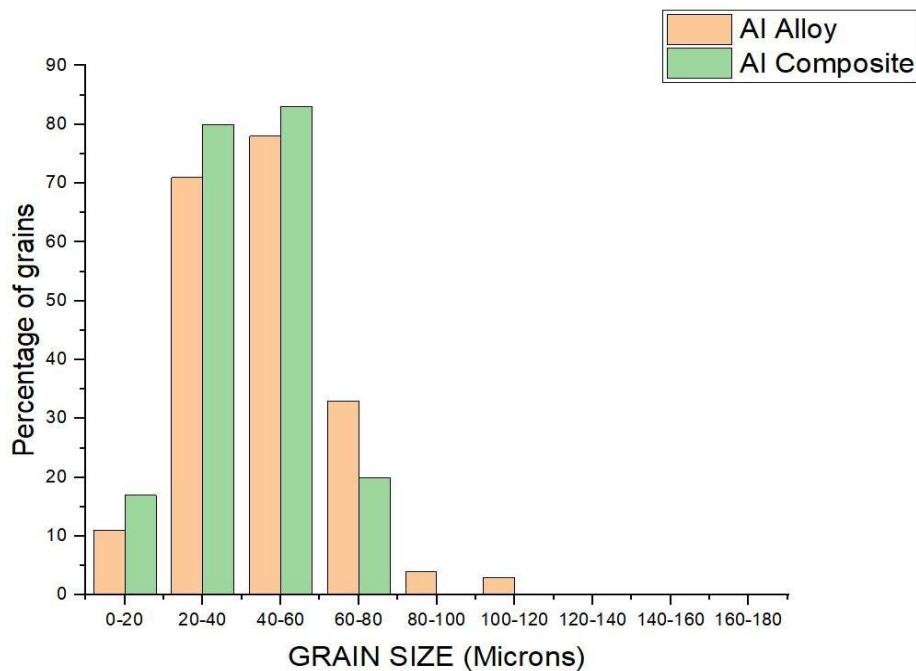


Figure 6.6 Comparative bar chart illustrating the grain size analysis result

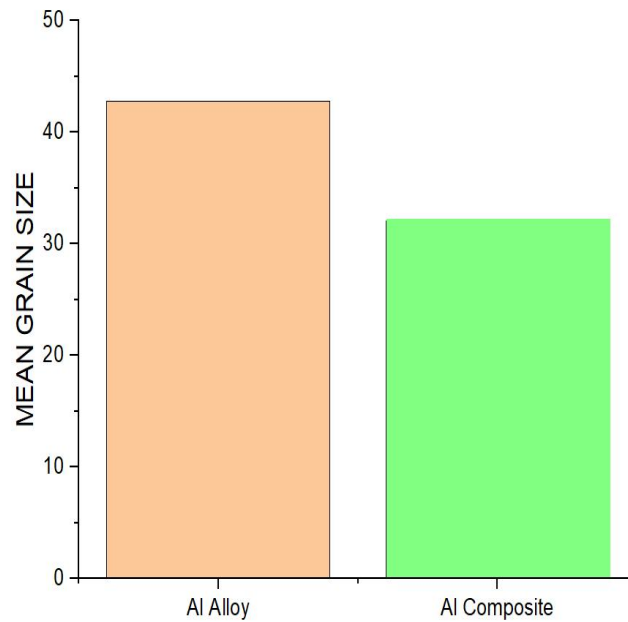


Figure 6.7 Mean grain size analysis result

6.3 ROCKWELL HARDNESS TEST RESULT

The samples undergo the standardized procedures for the Rockwell hardness test. The obtained results give important new information about the tested materials' hardness characteristics. As quantitative measures of the materials' hardness, the Rockwell hardness values (expressed on the corresponding scales, such as HRA, HRB, and HRC) are used. These findings support our understanding of the mechanical properties of the material, its suitability for particular applications, and its resistance to wear and deformation. Given its non-destructive nature, speedy completion, and broad applicability, the Rockwell hardness test has established itself as a reliable technique for determining the hardness of the materials under test. The consistency and dependability of the outcomes ensure their applicability in process optimisation, material selection, and quality control. Below is a summary of the Rockwell hardness test's findings.

Table 6.2 Hardness results of Al Alloy and Al Composite

Rockwell Hardness	Rockwell Hardness	Mean value (HRB)
Aluminium Alloy	50	51.5
	52	
	54	
	50	
Aluminium composite	65	64.5
	64	
	65	
	64	

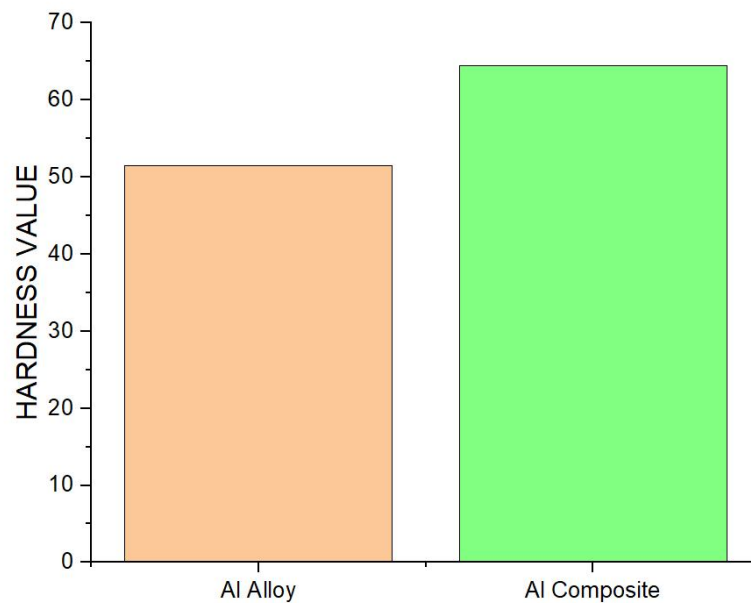


Figure 6.8 Comparative bar chart illustrating the Hardness result

- Moving from aluminium alloy to the composite material results in a 20% increase in hardness.
- The composite material is generally harder and more resistant to dents or scratches because it has a higher hardness value (64.5) than the aluminium alloy (51.5).
- In general, materials with a higher hardness tend to be less ductile. To determine each

material's capacity for plastic deformation prior to fracture, it would be crucial to assess its unique ductility properties.

A material with a higher hardness is typically regarded as being superior to a material with a lower hardness in terms of wear resistance and its capacity to withstand indentation or scratching

6.4 CHARPY IMPACT TEST RESULT

A common technique for assessing a material's mechanical properties, such as impact strength, is an impact test. Typically, a Charpy impact machine is used for the test, which applies a sudden load to the specimen from a fixed height, causing the specimen to break. The steps for the test include setting up the specimen, mounting it, loading it, running the test, and recording the angle. We can determine the impact strength of the specimen based on the discrepancy between the free angle (103°) and the obtained angle. Each was tested using four samples in the experiment. These samples' average values were computed to represent the impact strength of both the alloy and the composite.

Table 6.3 Impact results of Al Alloy

	Angle	Impact energy(J)	Mean value
Sample 1	97	24.73	22.65J
Sample 2	97	24.73	
Sample 3	98	20.58	
Sample 4	98	20.58	

Table 6.4 Impact results of Al Composite

	Angle	Impact energy(J)	Mean value
Sample 1	99.5°	14.377	19.03J
Sample 2	97	24.73	
Sample 3	98.5	18.51	
Sample 4	98.5	18.51	

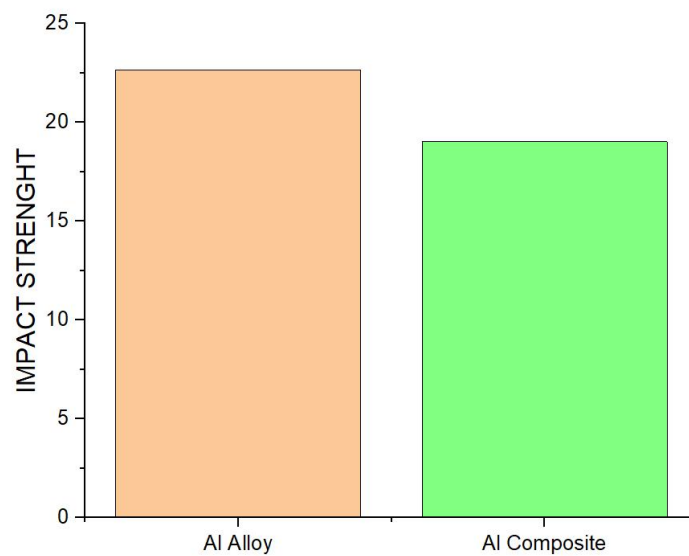


Figure 6.9 Comparative bar chart illustrating the impact result

- Impact energy is reduced by 16% when switching from aluminium alloy to composite material.
- The impact energy of the 1350 aluminium alloy is recorded as 22.65 J, whereas the impact energy of the aluminium composite material is 19.03 J.
- Impact energy refers to either the material's ability to absorb energy or the amount of energy needed to fracture or deform the material under impact.

- The analysis of the two materials shows that the impact energy value of the 1350 aluminium alloy is greater than that of the aluminium composite. This suggests that when compared to aluminium composite material, the 1350 aluminium alloy can withstand more impact forces before breaking or deforming.
- Materials with higher ductility typically resist fracture under impact loads better. Higher impact strength can be achieved by a material's capacity to deform and absorb energy during an impact event. This prevents sudden brittle failure.
- The composite material exhibits less ductility than the alloy, according to the impact energy value. This is a predictable result because the composite can become more fragile as a result of the reinforcement. It is clear that the composite still maintains a respectable level of ductility despite having slightly less impact energy than the alloy.

6.5 SEM ANALYSIS

The fractured portion is then examined under a scanning electron microscope after the impact test. SEM analysis of both alloy and composite materials enables a thorough analysis of the microstructure and surface properties of the material that has fractured. The SEM analysis's findings are depicted in the figure below. The first figure shows a SEM image of an aluminium alloy base matrix, and the second shows a SEM image of an aluminium composite.

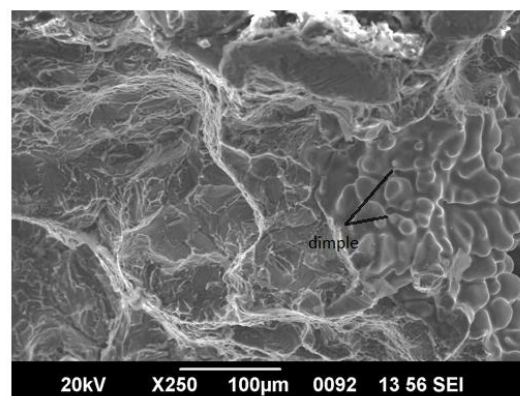


Figure 6.10 SEM analysis of alloy

Dimples found in the SEM analysis of an alloy of 1350 aluminium have important effects on ductile deformation and corrosion behaviour. They may increase surface area, which might encourage localized corrosion, but they may also disrupt continuous corrosion layers, which slows down the rate of corrosion overall. In SEM images of the alloy, small depressions or cavities on the surface are evidence of ductile deformation, which is linked to dimples.

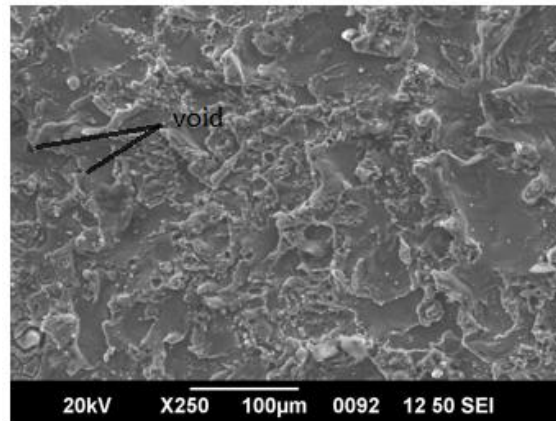


Figure 6.11 SEM analysis of composite

The aluminium composite's mechanical properties were significantly impacted by voids, according to the SEM analysis. In addition to decreasing impact strength and ductility, voids also increase susceptibility to crack initiation and propagation by acting as stress concentrators. Voids caused stress to be redistributed, resulting in concentrated areas of high stress. Low impact strength and brittle behaviour were linked to cleavage cracks. Void formation resulted in decreased strength, reduced stiffness, and crack vulnerability. Evaluation of fracture surface characteristics revealed information about brittleness and ductility. Insufficient mixing, poor compaction, and incompatible components were potential causes of void formation.

6.6 CORROSION TEST RESULT

Testing for electrochemical corrosion is a useful method for assessing a material's susceptibility to corrosion. Impedance, corrosion rate, corrosion current, and open circuit potential are all significant data points provided by this method. By measuring the material's electrical response to an applied potential or current, impedance measurements assist in determining the material's corrosion resistance. Measurements of corrosion rate and corrosion current quantify the rate at which corrosion occurs, enabling comparisons of various materials or assessments of corrosion prevention techniques. The material's electrochemical activity in its unprocessed state is indicated by the open circuit potential. Electrochemical corrosion testing analyses these parameters to reveal information about a material's corrosion resistance and performance, assisting in the choice of a material, the creation of corrosion prevention plans, and the evaluation of material deterioration over time. We obtain a variety of values from this electrochemical corrosion testing, including open circuit potential, impedance, corrosion rate, and corrosion current.

6.6.1 Open circuit potential

In the absence of an external current, open circuit potential is the electrical potential difference between an electrolyte surrounding a metal surface and that surface itself. It helps determine a material's susceptibility to corrosion and sheds light on its electrochemical behaviour. The onset or development of corrosion can be detected by changes in the open circuit potential. It is possible to predict the long-term durability of materials in various environments and comprehend the behaviour of corrosion by keeping an eye on this parameter. The open-circuit potential values for both the base matrix alloy and the composite material are shown in the graph below. It displays the potential variations between the two materials when the circuit is open.

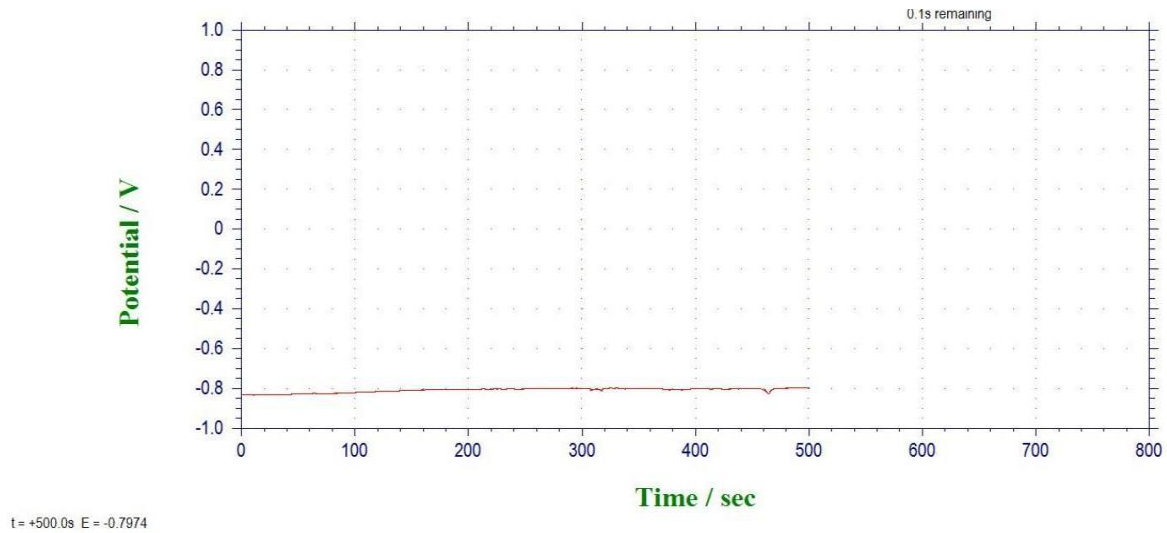


Figure 6.12 ocp plot of aluminium composite

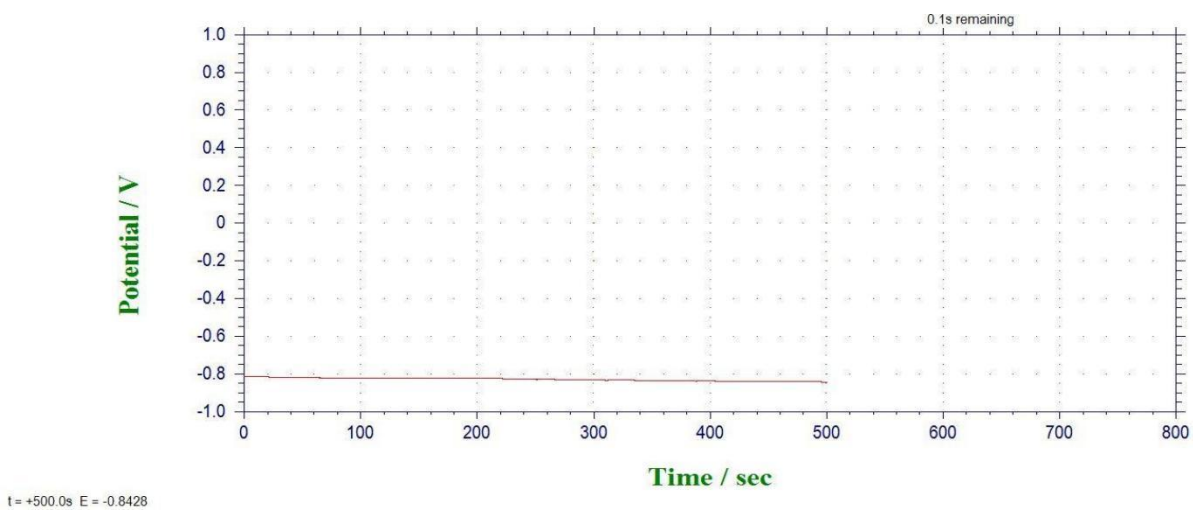


Figure 6.13 ocp plot of aluminium alloy

6.6.2 Impedance

Impedance is the measurement of a material's resistance to the flow of an alternating electrical current and is used in electrochemical corrosion testing. It is an important parameter for evaluating how corrosion behaves and how well materials perform. Impedance measurements reveal details about a material's intricate electrical reaction to an applied potential or current. Insights into the material's resistance to corrosion processes, such as the formation of protective oxide layers, can

be obtained by analysing the impedance spectrum. Impedance measurements are frequently used to compare the corrosion resistance of various materials and assess the effectiveness of corrosion protection techniques.

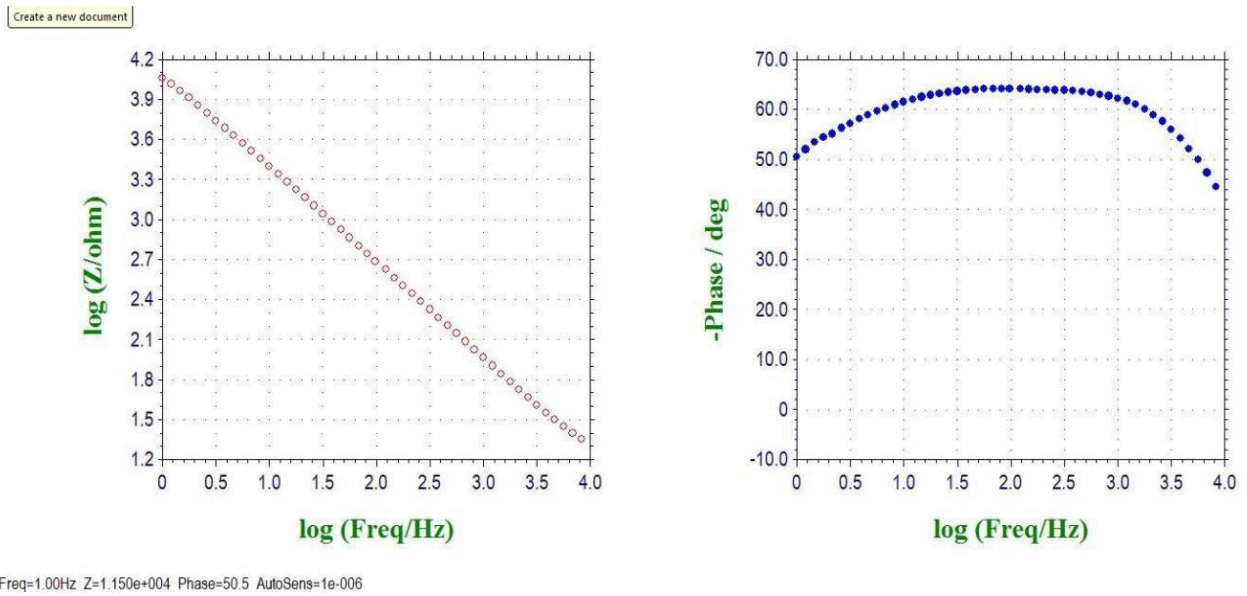


Figure 6.14 Bode plot of aluminium composite

Impedance value of composite, $Z = 1.150+004$

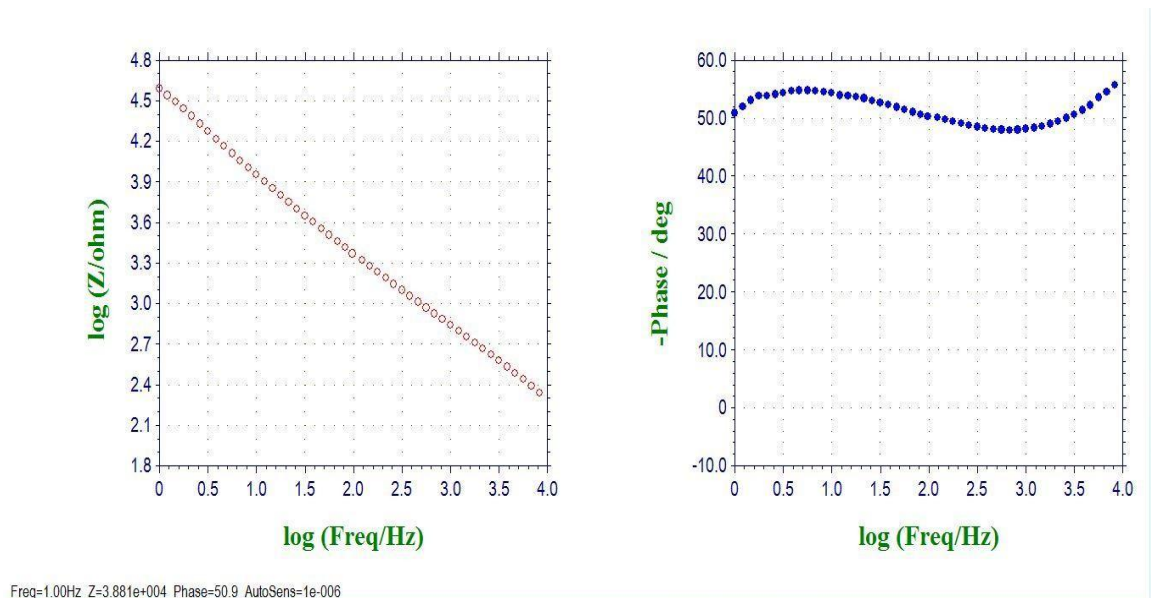


Figure 6.15 Bode plot of aluminium alloy

Impedance value of alloy, $Z = 3.881e+004$

6.6.3 Corrosion rate and corrosion current

Important factors in corrosion testing include corrosion rate and corrosion current. The corrosion rate, which is typically expressed in mils per year or millimetres per year, gauges how quickly a material deteriorates over time as a result of corrosion. The flow of electrical current connected to corrosion reactions is measured as corrosion current. These measurements aid in assessing corrosion severity, evaluating corrosion prevention strategies, and comparing the corrosion resistance of various materials. They are essential to comprehending and handling corrosion-related problems in various industries. The base matrix alloy and the composite material's corrosion rate and current values are depicted in the graph below. The relationship between the applied potential and the resulting corrosion current is shown by this plot, also called a Tafel plot.

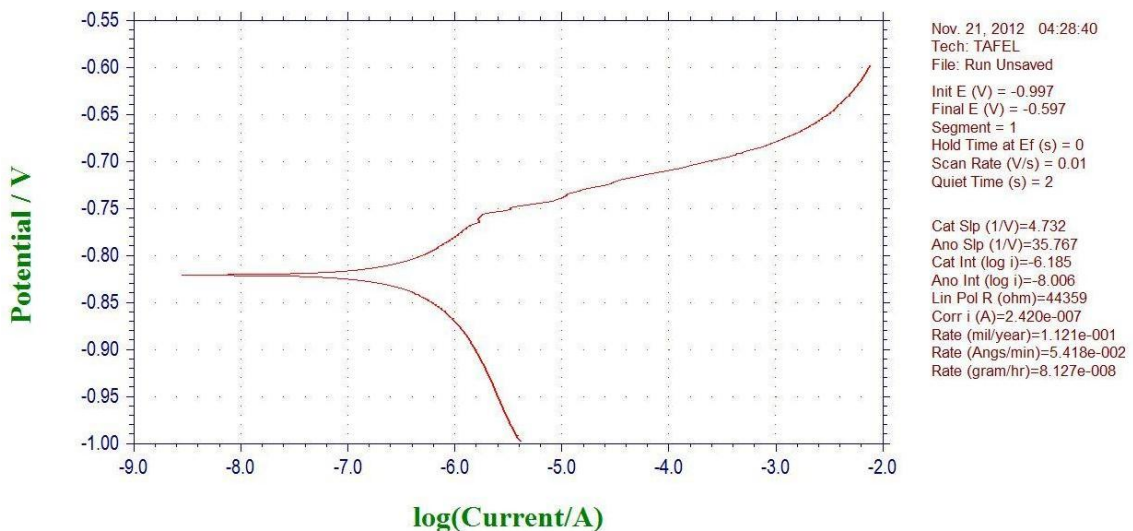


Figure 6.16 Tafel plot of aluminium composite.

Corrosion current, $i = 2.420e-007$ A

Corrosion rate, $r = 1.21$ mil/year

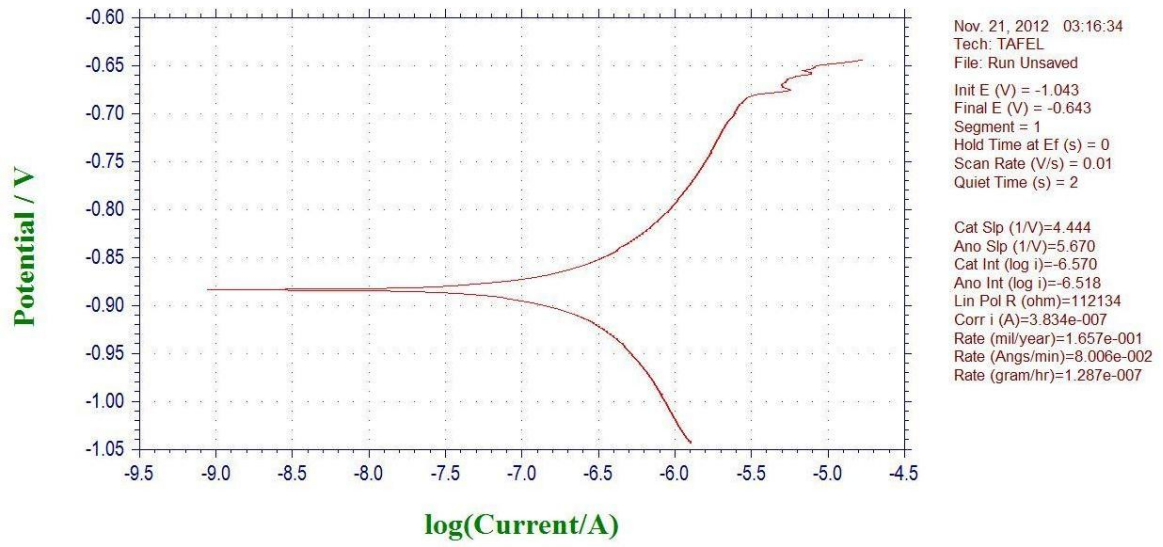


Figure 6.17 Tafel plot of aluminium alloy

Corrosion current, $i = 3.834 \times 10^{-7}$ A

Corrosion rate, $r = 1.657$ mil/year

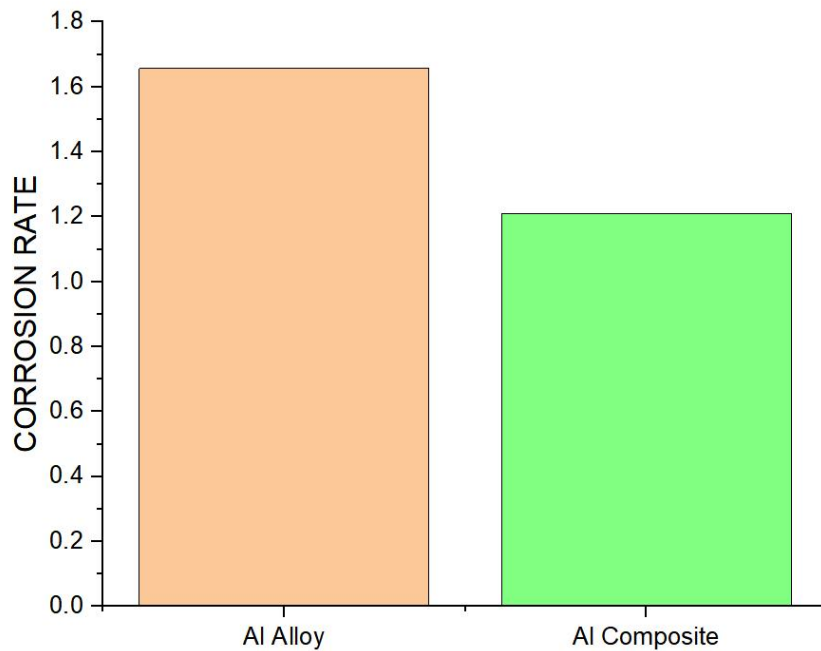


Figure 6.18 Comparative bar chart illustrating the corrosion rate analysis result

- (i). The corrosion rate is reduced by 26.9% when switching from aluminium alloy to composite material.
- (ii). When compared to the aluminium composite, the aluminium alloy exhibits a higher corrosion rate and corrosion current, indicating that it is more susceptible to corrosion. This suggests that the alloy is more susceptible to corrosion-related degradation.
- (iii). The corrosion resistance of the aluminium composite is higher than that of the aluminium alloy. The composite appears to provide enhanced defence against corrosion attacks given the lower corrosion rate and corrosion current, especially when reinforced with boron carbide and coconut shell ash.
- (iv). The aluminium composite has greater corrosion resistance than the aluminium alloy. Given the lower corrosion rate and corrosion current, the composite seems to offer improved defence against corrosion attacks, particularly when reinforced with boron carbide and coconut shell ash.
- (v). The inclusion of boron carbide and coconut shell ash as reinforcement materials in the aluminium composite is essential for lowering the rate of corrosion. These reinforcements serve as defences against corrosive attacks, increasing the corrosion resistance of the composite as a whole. It is crucial to remember that while reinforcement has a noticeable impact on slowing down corrosion, coconut shell ash can also have a negligible effect on the corrosion rate, possibly increasing it slightly.
- (vi). The findings emphasise the significance of material choice in corrosive environments. As a result of the decreased rate of corrosion in seawater environments, marine structures, pipelines, subsea technology, marine vessels, and coastal infrastructure can all benefit from increased durability and lower maintenance cost.

CHAPTER 7

CONCLUSION

This study examined the creation of aluminium composites with reinforcements made of boron carbide and coconut shell ash in order to examine the potential advantages and characteristics of these composites. The composites were successfully created using a stir casting process, with weight percentages of 1.25 for both boron carbide and coconut shell ash. The results of this study provide important new information about the corrosion resistance, impact strength, hardness, and environmental sustainability of these aluminium composites. For assessing the suitability of these composites in various applications where improved mechanical properties, weight reduction, and corrosion resistance are desired, it is essential to be aware of these key factors.

The major conclusions are :

- (i). Using boron carbide and coconut shell ash as reinforcements at a weight percentage of 1.25% each, aluminium composites were successfully made, proving the viability of incorporating these materials into the composite.
- (ii). The impact strength of the aluminium composite was reduced by 16% when compared to the base matrix alloy, demonstrating a trade-off between increased hardness and decreased toughness. This reduction emphasises the need to take into account the particular specifications for impact resistance in pertinent applications.
- (iii). The aluminium composite gained 20% more hardness after the addition of coconut shell ash and boron carbide reinforcements. The hard reinforcing particles, which effectively strengthen the composite material and imply improved resistance to deformation and wear, can be credited for this improvement.

- (iv).The corrosion rate for the aluminium composite was significantly lower than for the base matrix alloy, declining by 26.9%. Due to the addition of reinforcements made of boron carbide and coconut shell ash, the corrosion resistance of the composite material has improved, making it particularly suitable for environments where exposure to moisture or corrosive substances is a concern.
- (v). In comparison to aluminium alloy, the optical images of aluminium composite show a rise in pores. The aluminium composite's mechanical attributes will be impacted by this.The grain size is smaller in aluminium composite compared to that of aluminium alloy.
- (vi).The density of the aluminium composite was reduced by 3.7% as a result of the addition of lightweight reinforcements. This decrease in density makes the composite material suitable for weight-sensitive applications because it offers benefits like increased performance overall, reduced transportation costs, and improved fuel efficiency.
- (vii). The study demonstrated the potential of coconut shell ash as a sustainable and economical solution by repurposing it as a reinforcement in the composite material. This finding emphasises the advantages of utilising readily available waste materials, helping to reduce waste and promote environmental sustainability.

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