DEVELOPMENT & COMPARATIVE STUDY OF COPPER ALUMNIUM METAL MATRIX COMPOSITE THROUGH DIFFERENT ROUTES

A thesis submitted in partial fulfilment of the requirements for the award of the degree of

Master of Technology in Material Engineering
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Submitted by

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DEDICATED

TO MY BELOVED FAMILY MEMBERS

CERTIFICATE

This is to be certified by **Mr. ARGHA GHOSH** (Examination Roll No: **M4MAT24005**; University Roll No: 002211303006; Registration No: 163733 of 2022-2023), a final year M.Tech student in Material Engineering of the 'Metallurgical and Material Engineering Department', Jadavpur University, who has completed his project entitled "**'Development and Comparative Study of Copper Aluminium Metal Matrix (Al-Cu) Composite through different routes**". He has submitted his thesis report for the partial fulfillment of the curriculum for the degree of Master of Technology in Material Engineering from Jadavpur University. To the best of my knowledge, the contents of this thesis or any part thereof have not previously been submitted for the award of any degree or diploma.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis, titled **'Development and Comparative Study of Copper Aluminium Metal Matrix (Al-Cu) Composite through different routes,'** encompasses a literature survey and original research conducted by the undersigned candidate as part of my M.Tech. degree in Metallurgical and Materials Engineering during the academic session of 2022-2024. All information in this document has been obtained and presented in accordance with academic regulations and ethical standards. I also declare that, in compliance with these regulations, I have diligently cited and referred to all findings and results that are not original to this work.

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CERTIFICATE OF APPROVAL

The foregoing thesis, entitled as "***Development and Comparative Study of Copper Aluminium Metal Matrix (Al-Cu) Composite through different routes***" is hereby approved by the committee of final examination for evaluation of the thesis as a creditable study of an engineering subject carried out and presented by Mr. Argha Ghosh (Registration No: 163733 of 2022-23) in a manner satisfactory to warrantits acceptance as a prerequisite to the degree of Master of Technology in Material Engineering. It is understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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ABBREVIATIONS

Abbreviation	Full-Form
Al-Cu	Alumnium Copper
MMC	Metal Matrix Composite
PMC	Polymer Matrix Composite
CMC	Ceramic Matrix Composite
CuO	Copper Oxide
P/M	Powder Metallurgy
XRD	X ray diffraction
SEM	Scanning Electron Microscope
TEM	Transmission Electron Microscope
UFG	Ultra fine grain microstructure
UTS	Ultimate tensile strength
ECAP	Equal Channel Angular Pressing
CTE	Coefficient of thermal expansion
CYS	Compressive Yield Strength
FTIR	Fourier Transform Infrared Spectroscopy
HIP	Hot Isostatic Pressing
EDAX	Energy Dispersive X-ray Analysis
FESEM	Field Emission Scanning Electron Microscopy
Wd	Dry Weight
Ww	Wetty Weight
Ws	Submerged Weight
P,%	Porosity Percentage
VHN	Vickers Hardness
DPH	Diamond Pyramid Hardness
NDT	Non Destructive Testing
FEG	Field Emission Gun
BSED	Back Scattered Electron Detector (BSED)

NOMENCLATURE

Symbols	Description	Unit
T	Temperature	℃
t	Time	s
α	Coefficient of Thermal Expansion	m/m/°C
Δ	Deflection	mm
ρ	Density	kg/m^3
P	Load	N
Pa	Pressure	Kg or Ton
σ	Tensile Strength	Mpa
HR	Hardness	kg/mm^2

ABSTRACT

The aim of this thesis is to develop aluminium-copper composites via powder metallurgy technique. Copper oxide (CuO) is the source of copper. Copper is extracted simply reducing copper oxide into dextrose and the reaction is throughly examined and reported. Commercially available aluminium powder has been used as source of the aluminium. Aluminium-copper powder containing varying weight percentages of copper have prepared, uniaxially pressed using a hydraulic press. Subsequently, densification is achieved for all samples inside the specified temperature under controlled rate of heating. Upon completion of the heating process, the samples are gradually cooled slowly inside the furnace. The sintered composites are considered for various characterization and measurements like apparent porosity, density and mechanical properties. Composite samples are further considered for aging at low temperature. The aged composites are subsequently assessed for their mechanical properties. The effects of heat treatment on microstructural changes are investigated using optical microscopy, Field Emission Scanning Electron Microscope (FESEM). The results indicate a direct correlation between the increase in copper content and the enhancement of Vickers hardness values in an orderly and systematic manner. Aluminum, with its lower density compared to copper, not only contributes to composites with a high strength-to-weight ratio but also enhances stiffness and exhibits commendable mechanical properties surpassing those of pure aluminum.

CHAPTER - 1

Introduction

1. Introduction

Many metal matrix composites (MMC) have appeared in recent years, and aluminum-based composites are prominent in various industrial applications. These MMCs are cleverly designed to achieve an excellent strength-to-weight ratio and ideal stiffness properties. Although many studies have shown improved mechanical performance, a common challenge is limited flexibility. The plastic behavior of composites is intertwined with the use of the bonding matrix, a factor strongly influenced by the percentage and nature of reinforcements [1].

Copper oxide is an important precursor in many chemical reactions to produce various products [2-4]. Several processes have been proposed to completely reduce CuO, leading to the formation of metallic copper or CuO, which is considered to be the true active phase [5-9]. Investigation of the reduction of CuO by H_2 in situ is of primary importance. Ex situ studies of this system may not accurately describe the true state of the copper phase under reducing conditions [10-11].

Copper stands as a highly effective reinforcement material in metal-matrix composites (MMCs). Combining aluminum as the matrix metal with copper reinforcement enables the fabrication of MMCs through the powder metallurgical route. Powder metallurgy (P/M) emerges as a compelling processing technique for producing near-net-shape products and is widely employed in the fabrication of engineering components and particulate-reinforced metal matrix composites. The fundamental process in P/M technology involves the mixing and blending of powders, followed by the consolidation of the mixture and sintering of the consolidated powders to achieve densification [12].

Heat treatment stands as one of the pivotal methods for enhancing the mechanical properties of aluminum alloys, exerting a profound influence on microstructure of the composites [13]. Al-Cu alloys containing a copper content of up to approximately 5% are specifically tailored for heat treatment, also known as precipitation hardening. Copper emerges as one of the most significant elements in aluminum alloys owing to its high solubility and potent strengthening effect. In precipitation hardening, or age hardening, Al-Cu alloys undergo aging at elevated temperatures [14]. However, diverse age-hardening behaviors have been observed in aluminum matrix composites fabricated via powder metallurgy. Scientific literature indicates that, on the one hand, composite materials exhibit rapid hardening and reach peak hardness much earlier compared to the unreinforced alloy, suggesting an accelerated aging characteristic facilitated by the reinforcement [15, 16]. A significant challenge in the production and widespread application of composites lies in the cost of raw materials. However, scientists and researchers are actively addressing this issue by focusing on the development of composites utilizing reinforcement materials that are relatively low in cost [17].

The aims of current research is to delve into many different aspects, including the reinforcement behavior exhibited by varying weight percentages of aluminum, the reduction process of copper oxide, the influence on mechanical properties, the behavior of age hardening, and the evolution of microstructure.

CHAPTER – 2

Literature Review

2.1. Introduction

Literature survey is crucial because it provides a framework for ongoing research. The purpose of this section is therefore to bring together previous knowledge and decisions from previous studies on similar problems. Literature reviews inspire new research, which in turn encourages further literature studies. The fact is that one exerts influence over the other, which is why science, as a worldwide field, is constantly developing and evolving. The goal of the literature review is to highlight the significance of the current investigation and provides background knowledge on the topics that will be covered in current thesis. The information on the physical, mechanical, thermo-mechanical, and deformation behavior of metal and metal alloy composites that has been accessible for a decade now is summarized in this chapter. The subjects that were briefly described still require investigation to enhance the aforementioned qualities for various applications. Additionally, a number of crucial factors have been disregarded by earlier researchers, including the kinds of reinforcements, their size and shape, etc.

2.2. Study about Composite Materials

In essence, composite materials are developed by combining distinct material qualities to create an integrated effect. For any given application area, a variety of materials must be tuned to certain qualities. Applications for composites have expanded quickly, and this trend is sure to continue. Composite materials are adaptable substances with a wide range of uses. The need for engineers skilled in the development of structures composed of composite materials has increased due to the growing usage of these materials in numerous engineering applications. Nowadays, composites are recognized engineering materials that provide longevity and weight savings for a wide range of quickly developing applications.

In their most basic form, composites are made up of more than one material that has distinct chemical or physical characteristics. They combine to form a material that has distinct properties from what they had alone. The structure of the matrix & fiber are a composite's two primary parts. The fiber serves as the material's reinforcement, whilst the matrix serves as the foundation. Composites can incorporate core materials, fillers, additives, or surface treatments in addition to fiber reinforcements & matrix to offer special performance benefits.

Give a few instances of naturally occurring composites. Wood, as example, comprises a lignin matrix reinforced by cellulose fibers, whereas bones have bone-salt plates formed of calcium and phosphate ions that support soft collagen [18].

Combining more than one substance to create a composite requires additional work than using standard monolithic metals like aluminum or steel. What are the benefits of adopting composites versus metals?

Monolithic alloys & metals are unable to match the needs of today's modern technology. The performance criteria can only be met by combining multiple materials. Trusses or benches used to construct satellites, for example, must remain stable in dimensions in space when temperatures fluctuate between (-160°C) & (93.3°C). Coefficients of thermal expansion are typically limited to ($\pm 1.8 \times 10^{-7}$ m/m/°C). Monolithic substances cannot achieve these specifications, hence composites that consist of graphite or epoxy are the only materials that can. Composites are often more efficient. In the competitive airline industry, aircraft manufacturers strive to reduce total mass while maintaining stiffness and strength. Composite materials can be used to replace standard metal alloys. Composite materials may be more expensive, but their reduced assembly costs and fuel savings make them more cost-effective.

Mechanical advantage of composite measurement

We know that, when a prismatic rod is loaded in tension and the axial load is ‘P’ & for axial deflection is $'\Delta'$, and length of the rod is ‘L’ so, the elongation of a given rod is calculated as by the expression,

$$\Delta = PL/AE$$

Where, E refers to Young's modulus of elasticity for the rod's materials.

If the mass of the given rod is ‘m’ then it is also expressed as, $m = \rho AL$

Where, $\rho = density\ of\ the\ rod\ material$

So, $m = PL^2/4(E/\varphi)$

This equation suggests that the highest (E/ρ) ratio indicates the lightest beam for a given detection under a given load.

(E/ρ) is called as specific modulus which is suggest a mechanical advantages of the material and other parameter is called specific strength which is the ratio of ultimate tensile strength (σ_{ult}) & density of the material i.e.,(σ_{ult} /ρ).

Composite materials have high values for these two ratios. A graphite/epoxy unidirectional composite, for instance, may have identical strength as steel, but its specific strength is three times greater more.

Fiber factor affecting to improve the mechanical performance the composite material

In general, length, shape, orientation, and material are the four elements that increase mechanical performance.

(a) Length - There are both long and short fibers. Short fibers cannot be properly regulated for optimal orientation, whereas long, continuous fibers are simple to process and orient. Compared to shorter fibers, long fibers have numerous advantages. Impact resistance, minimal shrinkage, enhanced surface finish, and dimensional stability are a few of these. On the other hand, short fibers are inexpensive, simple to deal with, and have quick production cycle times. Because they are less flawed, short fibers are stronger.

(b) Shape - Due to their ease of handling and production, fibers are most frequently seen in a circular shape. Although it is possible to create fibers with hexagon and square shapes, their strength and high packing ratios are not worth the handling and processing challenges.

(c) Orientation - High levels of stiffness and strength are produced in a certain direction by fibers oriented in that direction. The directions of the fiber orientations will have great strength as well as stiffness if the fibers are orientated in multiple directions, like in a mat. It cannot, however, equal the stiffness as well as strength of directional composites for the same volume of fibers per unit volume of the composite.

(d) Material - A composite's mechanical strength is directly influenced by the fiber's material. It is typically believed that fibers will have excellent strength and elastic modulus. Graphite, aramids, and glass have dominated the fiber industry for composites due in large part to this expectation and affordability [19, 20].

Various matrix factors to improve the mechanical performance of the composite

The matrix's roles include holding the fibers together, insulating them from the elements, preventing handling-related damage, and dispersing the weight among the fibers. While matrices on their own often possess lower mechanical qualities than fibers, the matrix greatly influences the composite's mechanical attributes. These characteristics include compressive strength, inter-laminar shear strength, transverse modulus and strength, shear modulus and strength, heat resistance, and fatigue strength.

Another factor that may help to increase the performance of the composite material, an interface may be formed by reaction, mechanical or chemical bonding. Typically, multiple forms of bonding take place. Between the material's surface and the framework, a chemical connection forms. While some fibers automatically attach to the matrix, others do not. Adding coupling agents is a common way to create a chemical connection. A mechanical bond between the fiber and matrix may be formed by the etching or inherent roughness of the fiber surface that causes interlocking. The matrix will longitudinally shrink more than the fiber if its thermal expansion coefficient is greater than the fiber's and its manufacture temperatures are higher than the operational temperatures. The matrix compresses around the fiber as a result. When atoms or molecules from the matrix and the fiber diffuse into one another at the contact, reaction bonding takes place. A unique interfacial layer known as the inter-phase, having characteristics distinct from those of the fiber or matrix is frequently produced by this inter-diffusion. This thin interfacial layer creates microcracks in the fiber even though it aids in bond formation. Because of these microcracks, the fiber's & the composite's stiffness are both decreased. The qualities influenced by the matrix can be diminished and composites can fail due to weak or broken interfaces. They moreover let the fibers to be attacked by environmental dangers like wetness and heated gasses. Weak debonding at the fiber–matrix interface is favorable in ceramic matrix composites, even though a strong binding is necessary to transfer loads between the matrixes to the fiber. Matrix cracks are blunted and diffused along weak surfaces. This is the primary factor increasing the toughness of these composites to five times that of monolithic ceramics [21, 22].

2.3. Classification of composite materials

Composites are classified by the various ways, it may be classified as (i) Natural and (ii) synthetic .Natural Composites are Wood which is comprises as lignin and cellulose, human body which is as bones and tissues, bones are organic and inorganic.

Man-made composites are two types i.e., phase composition and layered composition. Phase composition can be two types filled composites and reinforced composites. Layered composites are classified as laminated and sandwich. Reinforced composites are divided as reinforcement and matrix material. By the reinforcement geometry, it can be classified as three type fibrous, particulate and flake. By the matrix material it is grouped as PMC (Polymer Matrix Composite), MMC (Metal Matrix Composite, CMC (Ceramic Matrix Composite). Fibrous is also divided by two types which is continuous and discontinuous. Discontinuous can be random or oriented. Oriented are uni-axially, bi-axially, tri-axially and multiaxially. Another types as particulate composites are dispersion strengthened and particle strengthened.

A different kind of composite material is called as nano-composite. Materials of a nanoscale (10–9 nm) size make up nanocomposites. When one of the constituents is less than 100 nm, the mixture is said to be a nanocomposite. Materials have different qualities than the bulk material. Modern composite materials often consist of micro scale (10–6 um) constituents. Most of the qualities of the resulting composite material are superior to those at the microscale because of the materials' nano-scale composition. Not every property of a nano-composite is improved; toughness and impact strength might sometimes decline. Applications of nanocomposites include military packaging, wherein sheets made of nano-composite exhibit enhanced characteristics including heat distortion, oxygen transport rates, & modulus of elasticity [23].

2.4. Study about Reinforcement

According to materials research, reinforcement comprises a component of a composite material that raises the stiffness and tensile strength of the material. When creating or choosing composite materials, the choice of reinforcing is crucial since, in many cases, the reinforcement determines the composite's qualities. Because reinforcements are often non-isotropic, or directionally oriented, their characteristics may vary in the three directions of X, Y, and Z. A unidirectional fiber composite, for instance, can have exceptionally high strength in the fiber direction because the fiber is carrying the majority of the load, and weak strength in the transverse direction because the resin matrix is carrying the load.

Composites were developed with high strength and weight ratios in mind, with reinforcements bearing a significant percentage of the load. Important considerations for composite design include both the form and chemical makeup of the reinforcement. Fabric fragments, fibers, or whiskers can all serve as reinforcement. These reinforcements are essentially utilized to improve a composite's mechanical characteristics.
The primary goal of the reinforcement is to furnish the composite with enhanced levels of strength and stiffness.

- In addition to their structural qualities, reinforcing materials (the graphite, glass, Sic, alumina) may also offer limited thermal expansion, wear resistance, & electrical and thermal conductivity.
- Fiber tows, an untwisted bundle of continuous filaments, are a very often utilized form of reinforcement in outstanding performance composite.
- PMCs, MMCs, and CMCs use fiber monofilaments, which are made up of a single fiber with a diameter of typically less than 100 µm.
- Particulates, which and chopped fibers are the most often applied reinforcement morphologies in MMCs, or PMCs as well.
- Platelets & whiskers are utilized in PMCs & MMCs to a lesser extent.

Typical forms of reinforcement include:

i. Unidirectional continuous tows.
ii. Bidirectional woven textiles and braided sleeves.
iii. Particulate fillers.
iv. Non-continuous chopped fibers (discrete fibers and fiber matting) [24].

2.5. Look into Matrix

As the fibers give the composite its fundamental strength and stiffness, the matrix material also significantly affects the composite's overall mechanical qualities. The load is not intended to be borne primarily by the matrix. Rather, the burden is distributed and the fibers are bound together by the framework. In addition, it gives the fibers ductility and shields them from surface harm. It divides the fibers and stops cracks from spreading from one to the other. Additionally, if a very flexible matrix is selected, it will help prevent the fibers from buckling during compression.

The ideal matrix material must be able to penetrate the fibers and create a solid interfacial bond. Additionally, it is critical that the fibers and matrix material do not come into contact chemically and that the matrix substance does not harm the fibers.

The primary responsibilities of the matrix are to:
(a) Transfer load between reinforcements by effectively transferring load from external forces to the reinforcement, the matrix enables the strength of the reinforcements to be utilized to the fullest extent possible.
(b) Bind the reinforcements together due to its cohesive and adhesive characteristics.

In addition to protecting the reinforcements from controlling and their surroundings, the matrix gives the composite a rigid structure, which is typically needed in a finished part and helps with handling during manufacture. As a continuous phase, the matrix, therefore, controls the transverse properties, inter-laminar strength, and elevated-temperature strength of the composite [25].

2.6. Study about Aluminium

On the surface of the earth, aluminum stands as the 3rd most plentiful element. Only silicon and oxygen are more prevalent. Up to a depth of 16 kilometers (10 miles), 8% of the Earth's crust is made of aluminum. The Earth is ranked seventh in terms of mass abundance of aluminum, with a total mass of 1.59%. Because less reactive metals sink to the Earth's core and aluminum rapidly forms oxide and becomes bonded into rocks, aluminum is more prevalent in the Earth's crust than it is in the universe as a whole. Aluminum is the third most prevalent element overall (after silicon and oxygen) and the most abundant metallic element in the Earth's crust (8.23% by mass). Aluminum is present in a wide variety of silicates found in the crust of the Earth. The Earth's mantle, on the other hand, contains only 2.38% aluminum by mass. Seawater also contains aluminum, albeit at a quantity of 2 μg / kg. Aluminum rarely appears in nature in its metallic form because of its great desire to mix with other common elements. However, its compounds play a significant role in almost all common rocks. It can be found in anorthosite, granite, syenite, slate, schist, and clay.

Aluminum is a light metal that weighs about one-third that of a same volume of copper or steel. It is ductile and silvery white in color, with a dull luster that is typically caused by an oxide surface coating. It is nonmagnetic, does not easily absorb neutrons, resists corrosion, is a great conductor of heat and electricity, reflects light and radiant heat, is safe to use with foods and medications, and can be created using any known metalworking technique.

In the Solar System, the quantity of aluminum per particle is 3.15 ppm (parts per million). After nitrogen and hydrogen, it is the third most plentiful element with an odd atomic number and the twelfth most abundant element overall. The universe's eighteenth most prevalent nucleus is 27Al, the only stable isotope of aluminum. It is nearly entirely produced by the fusion of carbon in huge stars that will eventually burst into Type II supernovas. This fusion produces 26Mg, which turns into aluminum when it absorbs free protons and neutrons. Smaller amounts of 27Al are produced in evolved stars' hydrogen-burning shells, where 26Mg can absorb free protons. Nearly all of the aluminum that is now in use is 27Al. Approximately 150 intermetallics between aluminum and other metals are known, and aluminum alloys well with most other metals (except group 13 and most alkali metals). Fixed metals are prepared by heating them in a specific ratio, then letting them cool gradually and annealing them. They have largely metallic bonding, and packing efficiency is what determines the crystal structure [26]. A variety of mechanical assembly, including screws, nails, and nuts and bolts, can be used to combine aluminum. These methods include brazing, welding, soldering, adhesive bonding, riveting, sewing, and stapling. It can be burnished, polished, buffed, abrasive blasted, and ground to a wide range of mechanical finishes.

Chemical working, and immersion plating, bright dips (which give metal an incredibly shiny surface), and alkaline or acid etches are just a few examples of the many chemical finishes that can be employed. It works well with the electrochemical anodizing process. Alternatively, it can be covered with organic coatings like paint, lacquer, or plastic sheets, or electroplated with other metals. Finishing techniques for aluminum include metalizing and porcelain enameling.

In the annealed state, high-purity aluminum (99.9 %) has a comparatively low tensile strength of approximately 50 Mpa (500 kg / cm, or 7,000 pounds per square inch). It is also relatively soft. (Annealing is the process of heating and then gradually cooling metal to reduce its brittleness.) However, it can be created by alloying and applying the appropriate heat and mechanical treatment. The solid metal expands by approximately 7% of its volume upon melting, with the solidification shrinkage amounting to 6.6% of the liquid content. The one gas that is known to be somewhat soluble in molten aluminum is hydrogen; when the metal cools, its solubility rises but eventually falls to almost nothing. Aluminum can function as a mild acid to generate salts with strong alkalies or as a base to form salts with acids. Because of a thin, transparent oxide film that forms when aluminum is exposed to air and shields it from more oxidation and reactivity, it is stable in air. This natural oxide coating grows self-limiting, meaning that it stops growing when a thin layer forms. Air-born molten aluminum is shielded from further oxidation by a thicker oxide layer. When precisely powdered aluminum flakes or atoms are combined with air and burned, they will detonate explosively. Metal hydroxide is created when metal and boiling water mix quickly to release hydrogen.

Pure aluminium (99.99 %), lacks strength and hardness but is formable, weldable, corrosion-resistant, and a superb electrical conductor. Pure aluminum is used in a variety of applications, including chemical equipment, reflectors, a catalyst in the production of gasoline, fine jewelry, and electronic components. The majority of aluminum used now is alloyed with other elements to improve its strength. Aluminum alloy goods can be produced into the desired form in a foundry using sand-casting, permanent-mold-casting, or die-casting, or they can be cast into cylinders or rectangular components that are then worked, or wrought, into products like sheet, plate, forgings, or extrusions. Aluminum generates a highly reflective layer when it evaporates in a vacuum, reflecting both heat and light. Unlike a silver coating, it does not corrode. Toys, landscape design paper, telescope mirrors, and packaging are just a few of the numerous applications for these aluminum coatings.

Since aluminum is flexible, lightweight, and inexpensive, it had replaced copper in electrical power lines by the early 1900s, more than making up for copper's inferior conductivity. Aluminum alloys are widely used in construction and can be found in appliances, pots and pans, utensils, TV aerials, roofing, windows, and cladding. They are also frequently found inside homes. Aluminum is the perfect packaging material for thin foils since it is strong, flexible, impermeable to water, and resistant to chemical attack. Put another way, it's perfect for shielding your favorite candy bar or a life-saving drug. Though hundreds of billions are made each year, the aluminum beverage can is arguably the most iconic form of aluminum. The naturally shiny surface of each can provides a visually appealing backdrop for the product name. Its lightweight construction can endure pressure of up to 90 pounds per square inch, which is three times greater than that of a regular automobile tire, but opening the contents is as easy as pulling on the tab. Even though the refining of aluminum consumes a significant amount of electricity worldwide, aluminum cans are recyclable and can be recycled again, saving over 95% of the energy needed to process the metal in the first place [27].

2.7. Study about Copper

The oldest metal that people have used is copper. It has been in use since the prehistoric era. Over 10,000 years have passed since the first copper was mined, and a copper pendant from 8700 BC was discovered in modern-day Iraq. Copper was being melted from basic copper oxides around 5000 BC. Being a native metal, copper can also be found in the minerals bornite, chalcopyrite, azurite, cuprite, and malachite. Among the most useful materials for engineering are Cu & Cu alloys. Copper's physical attributes, including strength, conductivity, which range resistance to corrosion, machining ability, & ductility, combine to make metal ideal for a variety of uses. Changes in production processes and composition can improve these qualities even more.

Based on its structural property, the crystal structure of copper is fcc. Physically, it has a yellowish red color, and when polished, it takes on a brilliant metallic sheen. Copper is a material that is malleable, ductile, and robust. Copper is an excellent option for deep drawing, spinning, wire drawing, and tube shaping because of these qualities. In addition, copper and its alloys have good electrical and thermal conductivity, good resistance to corrosion and biofouling, good machinability & the retainability of mechanical and electrical properties at cryogenic temperatures, and non-magnetic characteristics. Pure copper has a point at which it melts of 1083°C. Copper designation systems are techniques for identifying chemical compositions rather than specifications. The system created by the U.S. copper and brass industry is expanded upon by the approach used to identify copper alloys. The new Unified Numbering System for Metals and Alloys (UNS) system employs five digits before the letter C, replacing the previous three-digit system. The atoms of copper and gold or silver, which together comprise a group in the periodic table of elements, are fairly similar. All is conscious of copper's exceptional electrical conductivity, which is a function of its atomic structure. A cloud of free electrons specifically suitable for the passage of electrical current exists within the copper atom lattice. Additionally, the effective transfer of thermal energy is improved by this same cloud of electrons. Copper has remarkable corrosion resistance due to its unique combination of crystal and electrical structures. In order to create coherent coatings on the metal surface that shield the lattice from additional corrosion, the free electron cloud is easily accessible. The energy of the atomic attractions between the atoms holds them in place inside the structure. Copper's exceptional ductility and toughness are attributed to its unique face-centered cubic atomic configuration. Every metal undergoes deformation through a process known as slip. A force applied to the metal causes the atoms to slide past one another in groups when slip occurs. There are four of these planes in the copper cell. There are twelve ways for slip to happen if movement can happen in three different directions on each of the four planes. It turns out that in any metal construction, this is the maximum number of slide possibilities that exist. A metal is prone to deform compared to fracture and fail if it has a high probability of experiencing significant slide.

Even though it is a science, materials engineering is also a great art. Proper material design requires a thorough understanding of the qualities that the alloying elements can impart to the copper base metal, as well as a great deal of research and expertise. Knowledge of the economics pertaining to the manufacture of parts, materials, and end-use machines is equally important. The exceptional qualities of copper, and its alloys have assisted industries internationally because of their consistent output, broad accessibility, and affordable price [28].

The application of metal powders in powder metallurgy provides engineers with a way to save money on materials, minimize machining, and ensure a consistent product at a fair price. With this special metal-forming technique, items with tight tolerances and little scrap can be produced. Additionally, it makes it possible to create goods that are impossible to make using any other technique. The powder metallurgy (P/M) specialist can ensure a wide variety of mechanical and physical qualities and manage the density of products by carefully selecting powders. He has the ability to create combinations of metals that are insoluble in one another or combinations of metals and nonmetals that combine their respective qualities. components with porosities as high as 60% or, on the other hand, nearly pore-free sections with densities close to the metal's intrinsic density can be produced by adjusting the density. The density of a single section can also be changed. Moreover, the metallurgist can create pieces with connected pores to create a skeleton that can be impregnated with polymers, oils, or even metals with lower melting points. Additionally, copper is added to iron or aluminium powder components by infiltration or mixing in order to improve the mechanical characteristics and regulate dimensional changes during sintering. In addition to being utilized in a multitude of chemical applications, medals and medallions, metal-plastic decorative goods, brazing, cold soldering, and mechanical plating are among the non-structural uses for copper and copper alloy powders. Commercially available copper powder with a purity of above 99% copper has electrical conductivities of 80% to 95% IACS when crushed and sintered, and parts made from this powder have similar properties. By densifying even further, conductivities that are close to 100% IACS can be reached. While copper has typically melted, the liquid metal passes through an opening and is bombarded by a fast-moving stream of gas or liquid, typically water. This causes the molten metal to break apart into particles that solidify quickly. Three factors in particular affect particle size and shape: flow rate, pressure, and atomizing the press [29].

2.8. Study about Copper oxide (CuO)

A chemical having a monoclinic structure and semi-conductivity is copper oxide (CuO). As the most basic constituent of the copper oxide family, CuO has drawn special attention due to its many potentially valuable physical features, including spinning dynamics, electron correlation effects, and high temperature superconductivity. Relatively speaking, copper oxide is inexpensive, readily combined with polymers and polarized liquids (like water), and it has somewhat stable chemical and physical characteristics. Since highly ionic nano-particulate metal oxides may be generated with unique crystal morphologies and exceptionally broad surface domains, such as CuO, they may be especially useful antibacterial agents.

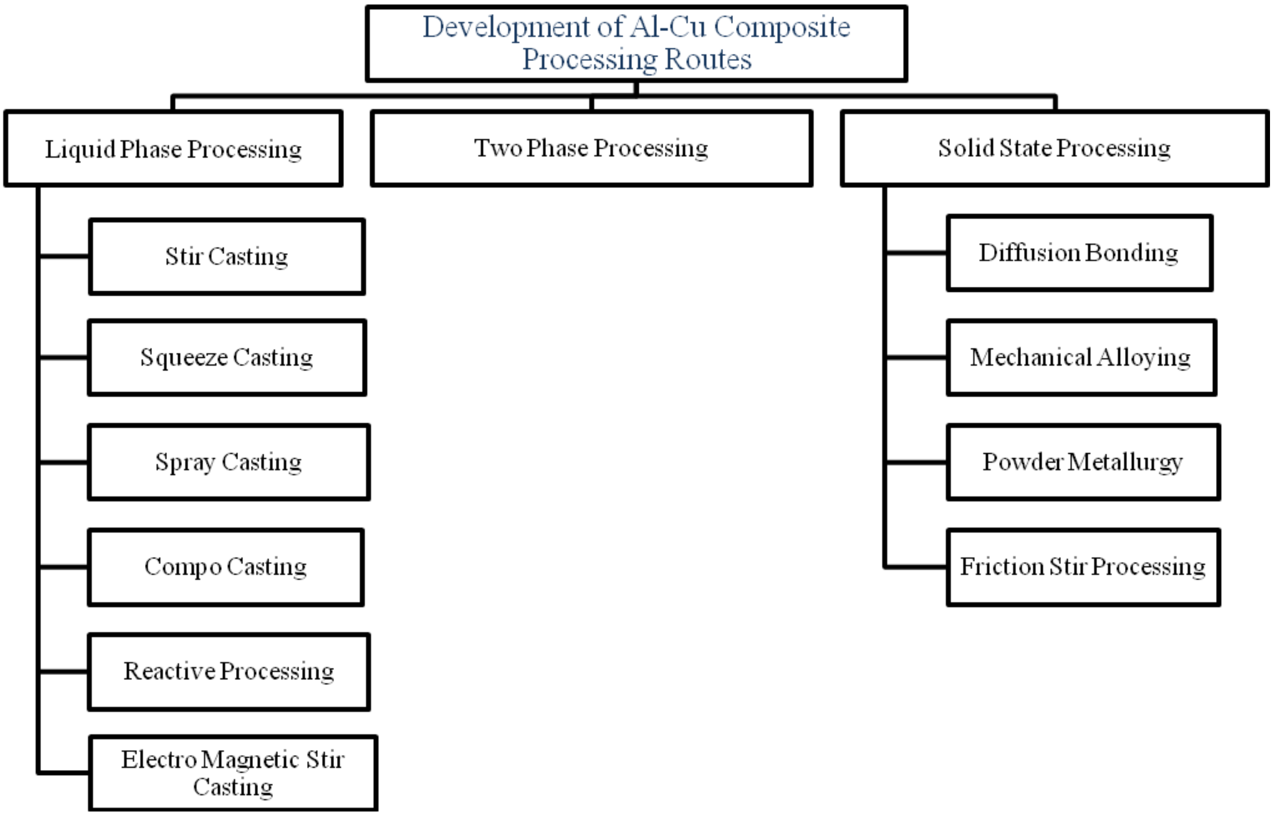
A study has been conducted on the development of copper films on copper (100), (11O), and (111) faces as well as on polycrystalline copper. These films were generated by reduction of copper (I) oxide and mixed Cu(I), Cu(II) oxide layers. While the orientations found in the copper(I) oxide layers were transferred to the thin films formed during reduction, it has been shown that Cu(II) oxide films regardless of orientation always produced polycrystalline copper. The distinct behaviors exhibited by the two oxides can be attributed to the variations in copper ion configurations within their respective crystal lattices, which are caused by the poor atomic mobility of copper at the reduction temperature of 300°C.

Some specifications of pure copper as its present as:

Molecular weight: 79.55; Appearance: Black to brown; Melting Point : >1200°C; Boiling point: 2000°C; Density: 6.31 g/cm^3; Exact Mass: 78.9245 g/mol.

Some importance present for CuO is as: as a catalyst for the combustion rate of rocket propellant. It can significantly reduce the pressure index, increase the pace at which homogenous propellant burns, and enhance its effectiveness as a catalyst for AP composite propellant. It may be used in a variety of disciplines, including the glass, ceramics, superconducting, thermoelectric, & sensing industries such as gas sensors, near-infrared tilters, magnetic storage devices, ceramic resistors, and photoconductive & photothermal applications. It also used in electronic devices, advanced superconductors & solar energy transformation [30].

2.9. Various Techniques used in the synthesis of Metal-Matrix composites



2.10. Study about Aluminium reinforced copper matrix composite (Al-Cu)

A manufacturing process for alloy metals made with the invention of copper and aluminum is disclosed. In these methods, the metallurgical combination of aluminium and copper is realized. In order to create higher production efficiency that is heavily influenced by scores of times and stable product quality, which encompasses a better, the combined strength provides a better aspect ratio and the bonding strength is high. Both copper and aluminum are significant non-ferrous metals that find extensive application in industrial and civilian settings. Copper has excellent conductivity, heat conduction, corrosion resistance, while aluminum possesses similar qualities. When copper and aluminum are compared, the resources for copper are scarcer, whereas bauxite is more plentiful and aluminum has a lower weight to price ratio. Copper and aluminum alloy combined metal band Alloy, as opposed to copper strip, is widely utilized in high-tech fields such automation, building trade, electronic computers, robotics, military projects, high- and low-voltage electrical equipment, and electric power. It is currently the subject of meta-research.

2.11. Various processing routes of Al-Cu Composites

When matrix metal and dispersion phase are bonded together in solid states at high temperatures and pressures through mutual diffusion, Metal Matrix Composites are created. This method is known as solid state processing. In contrast to liquid state fabrication of metal matrix composites, low temperature solid state fabrication approach suppresses unwanted reactions at the border between the matrix and dispersion (reinforcing) phases. After the sintering process, Metal Matrix Composites can also be deformed by rolling, forging, pressing, drawing, or extrusion. Either cold (below the recrystallization temperature) or hot (above the recrystallization temperature) deformation operations are possible. A desired orientation is obtained by deformation of sintered composite materials having a dispersed phase in the form of short fibers.

By the help of P/M techniques, Copper and aluminum powders are used in this experiment. The weight-to-Al and weight-to-Cu ratio is 95:5. Al and Cu are extracted from commercial grade for mixing. The powders are weighted in accordance with the compact's necessary dimensions. The aspect ratio is regarded as 1. In the ball mill, particles are evenly mixed. For eight hours, the blending process is carried out. The particles are compressed within a 25 mm circular die. The

Universal Testing Machine (UTM) is used to do the compaction. The ram is specified to be under 180 KN of load. MoS_2, lubricant oil, is rubbed onto the die walls to lower friction and stop powder from sticking. Because of the loose grain arrangement, the prepared green compact lacks the necessary strength. Sintering is done in order to achieve densification. Sintering's primary goal is to create chemical bonds while subjected to high temperatures. In theory, sintering occurs at a temperature between 70% and 80%.Sintering process is carried out in a muffled furnace at about a temperature range was 500 to 530^0C [31, 32, 33].

Through the process of powder metallurgy (P/M), aluminum metal matrix composites (AMC) were created, consisting of aluminum powder and cenospheres. Composites with cenosphere contents ranging from 10 to 50 vol. % were made and hydraulically dry-pressed. Microwave sintering was used to densify the composite materials. The goal of the project is to create an aluminum matrix composite using a powder metallurgy process, densifying the composite by microwave sintering, and using cenospheres as reinforcement. Porosity, thermal behavior, and compression strength of the composite are investigated.

The matrix was made using atomized aluminum metal powder that was 99.5% pure and had a particle size of approximately 75 μm, or ASTM 200 mesh, which was bought from M/s. NICE Chemicals, which makes laboratory reagent powder. Fly ash was used to create the cenosphere. The procedure that was used to extract cenospheres from the fly ash included making an ash slurry, churning it, and dispersing it. After then, the stirred slurry was let to calm to a stop. Later, the ash's light-weight floating material—which was mostly made of cenospheres—was taken out and allowed to dry. After drying, the material was sieved to get rid of cenospheres with different size fractions. In this investigation, cenospheres with an average particle size of 10–100 μm were used.

Dextrin solution, which was employed as a binder to help press the mix powder in the die and to provide green strength, was fully incorporated with the composite powders. To attain homogeneity, the mixing process was conducted in a mechanical laboratory mixer for approximately ten minutes. Using a hydraulic press and a force of 25 KN, the composite mixtures were formed into round pellets with a diameter of 40 mm and a height of 7 mm. Two batches of composite pellets were made: one batch was to be sintered in a microwave, and the other batch was heated using a traditional resistance method. In a microwave sintering facility running at 1.1 kW power and 2.45 GHz microwave frequency, one set of pellets was sintered at a temperature of 665 ±15^0C, or quite close to it. This multimode microwave was used with programmable controls and ran at 100% power. The sintering cycle lasted 90 minutes, including a 42-minute soaking and dwell period. The temperature was raised from ambient temperature to 670^0C during this time. The pellets were immersed at 665^0C for 42 minutes, with a heating rate of 12^0C per minute to reach this temperature. In order to facilitate sintering, the sample was held in the microwave sintering machine using a silicon carbide crucible, a microwave susceptor. The second set of pellets underwent conventional sintering for eight hours in a muffle type resistance furnace that was heated with a kanthal element to 670^0C. When compared to traditionally sintered composites, the porosity of the pure aluminum composites sintered in a microwave seems to be on the lower side. However, in both of the sintered samples, the porosity of the composites rose as the cenosphere concentration grew from 10% to 50% of the volume. When cenosphere content increased from 10% to 50% in microwave-sintered samples, porosity increased by 13.2%, while porosity increased by 16.8% in conventionally sintered samples [34].

By dispersing copper particles, or filings, in molten aluminum, stir-cast technique produces Al-Cu particulate composites (5 to15 weight %). Identical conditions for processing are also used to create Al-5%Cu alloy with mutual solubility. In the current work, an attempt has been made to fabricate Al-Cu (p) composites using the stir casting technique, with the reinforcements being copper powders that were produced using a conventional filing technique. The results are examined from the perspectives of microstructure and deformation (cold upsetting).

Additionally, the outcomes were contrasted with those of an alloy with an identical composition. According to the specific use, the metal powders are generally made by mechanical, physical, and chemical processes such as crushing, milling, grinding, shorting, atomization, electrolysis, chemical reduction, vapor condensation, and machining. The machining process is used to create chips, filings, turnings, and scratches. In the current work, a revolving copper rod is filed at high speeds using several grades of files to produce copper powders. Various rotation speeds and files are used to create powders of varying sizes. Powders are categorized using a sieve technique. In the current study, 99.9% pure aluminum serves as the foundational matrix material. Using a 3-phase bottom-pour electric resistance furnace with a Coverall (a patented chemical to prevent oxidation) lid, a pre-weighed quantity of aluminum is melted in a graphite crucible. The water in the bath is kept at 720°C. The basic vortex in the bath is produced by a three-blade mechanical stirrer that has been fitted to a 0.5 HP motor, coated with a thin layer of graphite and bentonite mixture, and completely dried. A predetermined amount of copper particles that have been completely dried in a muffle furnace at 200°C are swiftly and evenly added to the melt's vortex, causing the particles to become suspended in the melt. After 15 seconds of stirring, the melt is transferred into chilled, previously heated molds. 150 × 18 mm Φ composites with increasing copper concentrations and reinforcement sizes of +40, +50, +70, and +100 are created. Al-5wt% Cu alloy is also cast using comparable processing parameters. For twenty-four hours, the alloy and the composites are fully homogenized at 100°C. To understand the deformation behavior of the alloy and composites, standard samples measuring 27 mm by 18 mm Φ and having an aspect ratio of 1.5 are made. They have chamfered edges and 0.5 mm deep concentric grooves on parallel faces to hold lubricant. Prior to the test, each sample was grid marked at the midpoint in height. Deformation up to 50% is possible for Al-5% Cu alloy and composites with 5, 10, and 15% wt% Cu with particle size -50 + 100. Using both sets of end platens, upset tests were carried out at room temperature between two flat platens on a computer controlled servo hydraulic universal testing machine at a constant cross head speed. By upsetting the specimens with the aforementioned aspect ratio, plastic deformation was caused. Given that the alloy is made up of inter-metallic CuAl2 and a solid solution of aluminum, its extensive deformation makes sense.

Composites with comparable compositions are made of pure aluminum matrix and interface-containing copper particles as reinforcements. The matrix and reinforcement are composed of a range of alloys, from copper-rich to aluminum-rich, respectively. The propensity towards brittleness grows further when the volume fraction of copper particles increases. Composites containing more than 5% of copper have shown early failure. One of two possible causes for the early failure is the reinforcement particles' agglomeration or clustering as a result of higher volume percentages. Second, the base matrix's brittle nature as a result of the elevated copper concentrations has made the reinforcements' incompatibility with the matrix even worse. Fracture develops when microcracks grow more frequently in a direction perpendicular to the loading axis than in a parallel direction due to increasing deformations. The state of stress inside a particle cluster seems to encourage early particle cracking, interface debonding, and void formation in the ductile matrix, leading to early fracture, as the applied stress increases [35].

2.12. Processing methods of CuO to Cu

High-purity (99.995%) CuO powders were obtained from sources that are commercially available. At conditions between 150 and 300°C observed reaction with H_2 and reduction to metallic copper in our experiments using pure CuO powders. No change in the CuO diffraction pattern is observed in the first 15 minutes of the experiment; after this induction time, lines for metallic copper start to appear (direct $Cu2^{+}$ => Cu^{o} transformation) and water evolution is detected with a mass spectrometer at the reaction cell's exit. These are sequential reduction: $2CuO+H_2$ = >Cu_2O+H_2O & Cu_2O+H_2 => 2Cu + H_2O and direct reduction: $CuO+H_2$ = > $Cu+H_2O$. Reaction (2) is clearly dominant at 210 and 270 °C, but reaction (1) becomes significant at 300°C. Cu was shown to completely oxidize at extremely high temperatures. The oxidation process, which occurs between 30°C to 600°C.Cu^{1+} is not a stable intermediate in the reduction of CuO under typical process conditions, as demonstrated by in situ time-resolved XRD. A straight transformation of CuO => Cu transformation takes place in place of a sequential reduction (CuO => Cu_4O_3 => Cu_2O => Cu) [36].

2.13. Study about various properties in Al-Cu composite

2.13.1. Physical Properties

The physical-properties of powders encompass apparent porosity and density, compact density, angle of repose, flow rate, compressibility, and green strength. These characteristics for a particular powder composition could be influenced by moisture content, specific surface, granulo-metric composition, particle shape, and morphology, among other factors. The assessment of the behavior of powder during processing, which is achieved by their consolidation, is made possible by the knowledge of technological factors combined with its physical characteristics.

2.13.1.1. Porosity & Density

The weight of a unit volume of loose powder, expressed in gm/cm^3, is the apparent density of metal powder. This feature establishes the precise volume occupied by a mass of loose powder, which in turn establishes the processing parameters, including the range of press motions needed to pack and compact the loose powder and the design of the consolidation equipment. The apparent density is dependent on the particle size distribution and decreases with increasing surface roughness and irregularity in particle form. Because smaller particles fill the void left by the coarse particles, the apparent density of powders with a wide range of particle sizes increases.

2.13.1.2. Compression & compaction

The terms compressibility and compactibility refer to a powder's capacity to form un-sintered (green) compacts during die pressing. In general, the value of the compacting pressure needed to guarantee a particular green density of the sample is used to quantify compressibility. Consequently, a key consideration in the design of pressing machinery is the powder's compressibility. Typically, green density is used to express it. The compression ratio, or the ratio of the powder's apparent density to its green density, is another way to gauge its compressibility.

The green strength of a powder compact is used to assess compactibility, which is influenced by the fragility, intricacy, and ejectability of the compact from the die of the sample. In general, spherically shaped particles have a greater compressibility. On the other hand, a greater particle surface area, which may be attained by increasing the irregularity of the particle surface, usually results in a higher green strength. In addition, variables like raising the temperature and compaction pressure have opposing impacts on compressibility and green strength. The basis for better mechanical interlocking is enhanced by these elements, which also encourage intensive particle movement and deformation [37, 38].

2.13.2. Mechanical Properties

2.13.2.1. Hardness Behavior

Severe Plastic Deformation technique is developed due to the requirement for high strength and super-plasticity. The material's strength is closely correlated with its grain size. Thus, the production of Ultra-Fine Grain microstructure (UFG) is required. Specimens of aluminum (Al) are exposed to extreme plastic deformation. Because Al has a low strength, matrix work hardening is used to improve its mechanical properties by adding other materials. Al and Cu together exhibit increased hardness and strength in copper (Cu). An attempt is made to investigate the specimen's tensile strength, hardness, and elongation percentage qualities using copper and aluminum mixed in different weight ratio. To enhance the mechanical qualities of the Al powder without significantly altering its density, Cu powder is added. The primary cause of the improvement in mechanical properties is the specimen's average grain size being smaller. For the first pass, the ultimate tensile strength (UTS) of Al 5%Cu is 210 Mpa. For second pass, the specimen's UTS rises to 233 Mpa. Prior to ECAP, the tensile strength was 175.81 Mpa. During the third pass, the specimen fails. As the amount of copper in the specimen grows, so does its hardness. The Al 5%Cu specimen's hardness on the first pass is 36.8 BHN. The hardness value for the second pass is 38 BHN. The hardness value continues to rise as the applied strain increases. The hardness value was 35 BHN prior to ECAP. In this experiment, there was substantial plastic deformation of Al-Cu compaction. The specimen became consolidated, and mechanical properties like tensile strength and hardness improved with the addition of copper. During work hardening, elongation percentage dropped with the addition of Cu [39, 40].

Al-Cu alloy mechanical characteristics are assessed using the Hardness Vickers technique. The goal of this effort is to increase mechanical qualities by combining copper (Cu) and aluminum (Al) through a melting process. Al and Cu solids with a purity of above 98%, both melted at 1100 °C, are the starting ingredients. In these trials Cu additions of 3.8 weight percent, 4.4 weight percent, and 4.9 weight percent have been developed in order to improve mechanical properties. Al-Cu alloy mechanical characteristics are assessed using the Hardness Vickers technique. Microhardness tests at the surface cross section were used to assess the mechanical properties of Al-Cu alloys. The Vickers microhardness results, the highest value of 80 kg/mm^2 was obtained for Al-Cu alloy with Cu 3.8 wt%, while the lowest value was 20 kg/mm^2 for Al-Cu ingot with Cu 4.9 wt%. As the original Cu concentrations increased, the microhardness dropped as well [41, 42].

An attempt has been made to understand the mechanical characteristics, by altering the copper concentration between 5 to 15 weight percent. In this experiment, the basis matrix material is 99.5% pure aluminum. A Vickers hardness tester is used to record hardness values. When the alloy is cast, it exhibits less hardness than when it is homogenized. Hardness improved as particle content increased in both homogenized and cast environments. With higher particle concentrations, a good increase in hardness values of 10%, 50%, and 78% has been recorded in the cast condition. Lean alloy formation and low reinforcement concentrations, just 1.5% by volume are to blame for the poor increase at lower concentrations. While there is a hardness enhancement in the composite with the highest concentration, it is only 28% (78–50) effective, which is less than the 10% reinforcement addition [41].

For age-hardenable Al-Cu alloy, hardness behavior is quite different. Using a Vickers hardness testing equipment, the microhardness of the samples at various solution temperatures and aging durations was measured in order to study the age-hardening behavior of the Al-4%Cu matrix. In terms of increasing hardness, the GPII zone and intermediate are the most effective. Hardness is reduced as a result of the stable phase precipitating over time. There was no significant change in microhardness as a result of the aging process, independent of the aging time. The Al-Cu composite with 7% Cu exhibits the most increase in hardness after aging treatment in comparison of different weight percent like 1%, 3%, 5% and 7%. Consequently, compared to unreinforced Al-Cu alloys, the Al_2O_3/Al-Cu composite requires more Cu addition to achieve greater peak hardness. Effect of Cu content on Al-Cu composites hardness as a function of aging duration at 170^0C, 190^0C, and 210^0C, respectively. It is evident that for all aging temperatures, the age hardening rate of the composite rises as the Cu content increases. Peak hardness of the composite with 7% Cu appears at 11 hrs of aging temperature. In contrast, the peak hardness of the composites with 5% and 3% Cu content appears after 12.5 hr and 14 hr, respectively. Peak hardness is essentially absent at 1% Cu level, but at 7% Cu content, peak hardness rises by almost 20% relative to the solution state. The amount of $CuAl_2$ phase increases with increasing Cu concentration, which is the main cause of the composite's age-hardening effect. Compared to an unreinforced Al-Cu alloy, more Cu elements are required to create a sufficient amount of $CuAl_2$ phase in the matrix in order to achieve a higher age hardening effect. Nevertheless, due to over-aging, the hardness of the composite with 7% Cu concentration drops significantly after peak hardness. Therefore, choosing the ideal age period is crucial to getting the Al-Cu composites to

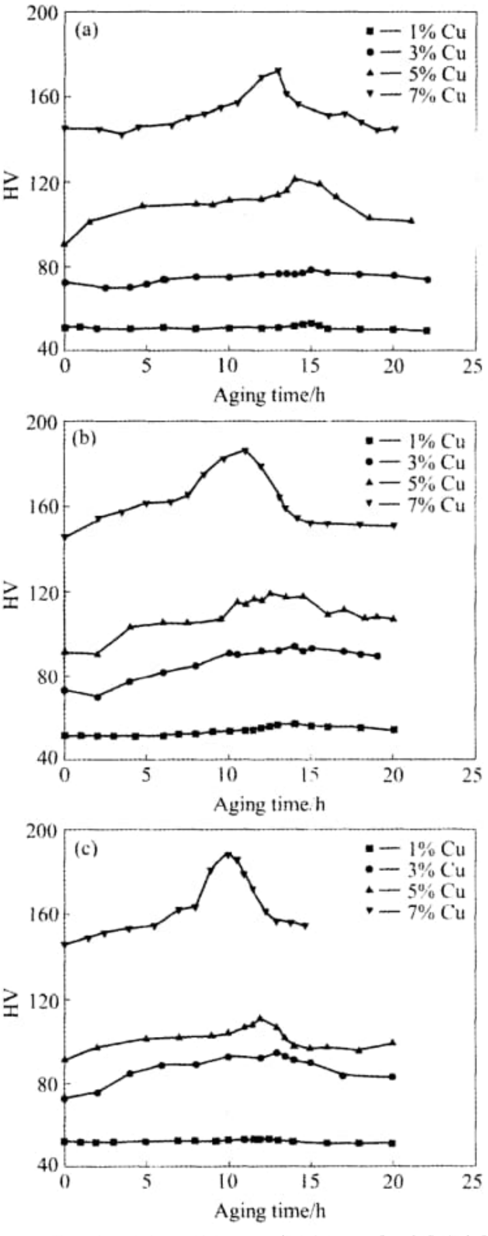


Fig. Effect of Cu content on hardness of Al_2O_3/Al-Cu composites as function of aging time during aging at 170 ℃ (a), 190 ℃ (b) and 210 ℃ (c)

reach their peak hardness [43].

Fig.2.1.1: Cu content in different weight % after aging

2.13.2.2. Coefficient of thermal expansion (CTE) behavior

Thermal characteristics and the coefficient of thermal expansion (CTE), have been measured for the sintered composites. The Coefficient of Thermal Expansion (CTE) of the composites for pure aluminum powder samples was 25.6 x 10^{-6}/0C, which is close to the predicted value for pure aluminum. When the cenosphere concentration increased from 10% to 50%, or from 20.7 to 7.3 x $10^{-6}/^{0}$C for the conventionally sintered samples, the CTE of the composites dropped .In comparison to samples that were sintered traditionally, the CTE of the composites in the microwave-sintered samples dropped as the cenosphere content declined from 14.3 to 3.6 x $10^{-6}/^{0}$C.[44]

2.13.2.3. Compressive Yield Strength behavior

Thermal shock resistance tests consisting of 5, 10, and 25 cycles were applied to the samples that were sintered conventionally and microwave-sintered. After undergoing a thermal shock resistance test, the compressive yield strength of the composites with 10% and 50% volume percentage were determined to be 83.4 and 69.4 MPa, respectively, for samples that were sintered conventionally. The values were 88.5 and 74.2 MPa for the microwave sintered samples with the same volume percentage of cenospheres. After 25 thermal shock resistance cycles, the compressive yield strength of 10 and 50 vol. % Cenosphere composite conventionally sintered samples dropped by 48.9% and 54.4%, respectively, and the compressive yield strength of the same vol. % microwave sintered samples decreased by 42.3% and 53.6%, respectively. Higher compressive yield strengths were observed in microwave-sintered samples for both composites [45].

2.13.2.4. Heat treatment and aging behavior

Al and Cu matrix alloy powders with a 4% percentage of Cu were used. When aluminum powder was atomized using argon gas, the average particle size was less than 63 um. An elongated, irregularly shaped particle with a comparatively smooth surface is the hallmark of aluminum powder. The dendritic shape of copper powder is typical of electrolytic production. Pure copper and aluminum powders were combined with silicon carbide particles in the proper mass proportions of the reinforcing phase to the matrix material for 30 minutes to create Al-4%Cu matrix alloy composites. The combined powders were then placed within a stiff die and compressed using a single-action compaction press at room temperature and 300 MPa of pressure. The compacts were sintered for one hour at 600°C in a nitrogen environment. In the furnace cooler, the sinters that had not been heat-treated cooled gradually at a pace of roughly 40°C.The heat-treated sintered composite samples were solution treated for six hours at 495 °C and 530°C, water quenched, and then aged for 4,12 and 24 hours at 180°C. The specified heat treatment conditions call for an aging treatment at 180 degrees Celsius and a peak hardening of the solution treatment between 495°C and 530°C. The study demonstrates that porosity affects the rate of aging, with porous materials deteriorating more slowly than thick materials. Because of its strong strengthening properties and high solid solubility in aluminum, copper is one of the most significant constituents in aluminum alloys. Two phases make up the alloy with a 4% copper content at thermodynamic equilibrium at room temperature: an intermetallic θ-phase (Al_2Cu) and a matrix made up of solid solution a. The goal of the solution heat treatment is to achieve a homogeneous solid-solution structure by dissolving the θ-phase particles. As the temperature drops, the maximum solid solubility of the copper in the aluminum matrix diminishes. The sequence of precipitation during age hardening in the studied Al-Cu alloy is as follows: GP zone→GP II zone$(\theta)'' \rightarrow (\theta)'$intermediate→$\theta$ (Al_2Cu).As a result, phases such as Al_2Cu that are meta-stable precipitated emerge before the equilibrium phase does [46].

2.14. Study about Various Characterization Techniques

The process of researching and analyzing a material's chemical, electrical, & physical characteristics is known as materials characterization. This is an important aspect of materials engineering study that aids in determining which material is best for a given application. A wide range of properties, including mechanical strength, thermal stability, electrical conductivity, and corrosion resistance, can be examined using advanced material characterization techniques. By using these methods, it is able to understand the material properties of various system components and optimize their designs for improved performance and dependability. This aids in their decision-making regarding their application in the development of safe and effective products as well as novel materials with tailored behaviors based on their intended use. The various techniques by which materials are characterized such as advanced imaging techniques like optical microscopy, SEM, TEM (Transmission Electron Microscopy),XRD, mechanical vibration analysis, TGA, spectroscopy analysis, FTIR, and others.

2.14.1. X-Ray Diffraction (XRD) methods

One of the non-destructive techniques for examining the structure of crystalline materials is X-ray diffraction, or XRD. X-ray diffraction (XRD) is frequently used to determine the source of unwanted deposits, evaluate the composition of materials, and detect mineral and metal compounds inside solid materials. The aluminum crystallographic planes (111), (200), (220), and (311) as well as the angles 38°, 45°,65°, 78°, and 83° were found by using X-ray diffraction (XRD) to characterize the textured surface structurally. Additionally, the copper (Cu) XRD peak was observed at 36.34°, 43.33°, 50.47°, and 73.57°, where the corresponding crystallographic planes are (111), (200), (220) & (311). CuO particles exhibit the biggest diffraction peak, with corresponding angles of (002), (-111), (111), and (200) and 2-theta values of 35.55°, 35°.57°, 38.41°, and 38.73°, respectively. The XRD patterns of three different weight percentages of Cu content in the Al matrix 5%, 10%, and 15% for hot-pressed composite samples at 600°C [40, 47, 49].Figure shows all the XRD graph which are illustrated below.

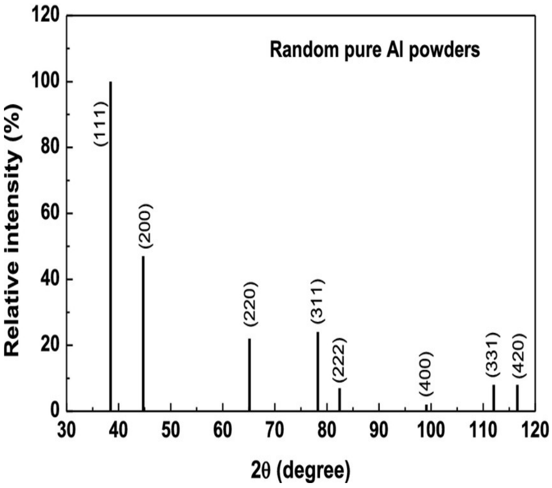


Fig. 2.4.1.1: Xrd of pure Aluminium showing

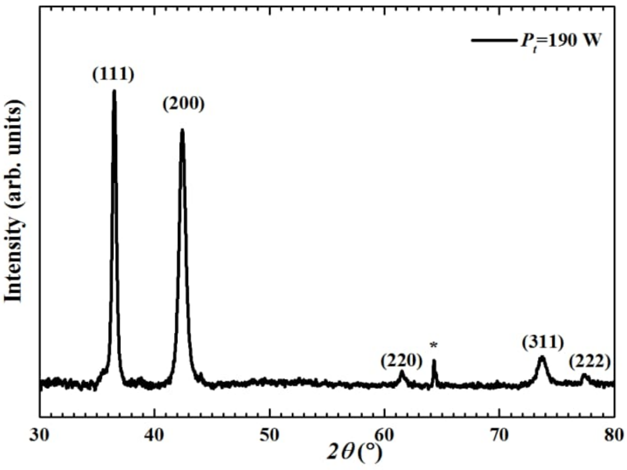
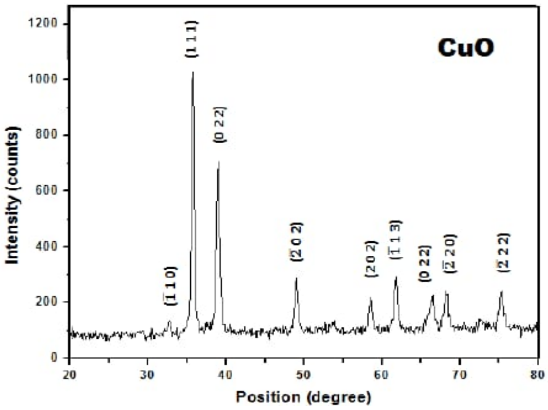


Fig. 2.4.1.2: Xrd of pure aluminium in Intensity



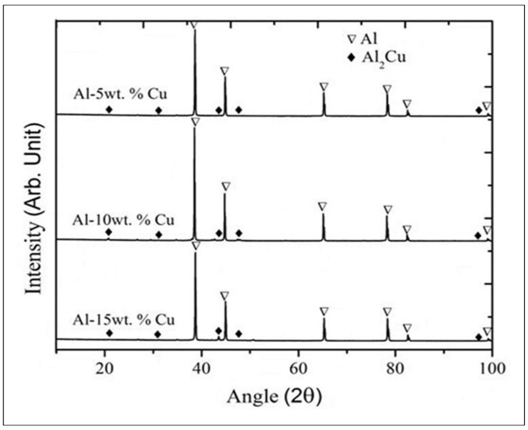


Fig. 2.4.1.3: Xrd of pure copper oxide

Fig. 2.4.1.4: Xrd of Al-Cu composite in (5%-15%)

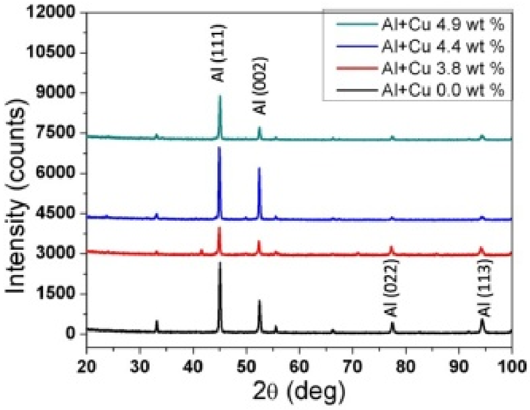


Fig. 2.4.1.5: Xrd of Al-Cu composite (3.8 - 4.9 wt%)

2.14.2. Microstructure Behavior

Concerns develop during the fabrication of metallographic specimens for powder metallurgy (P/M) materials when the material is not fully compressed by hot iso-static pressing (HIP). Material features visible at the micro scale are called microstructures. The terms "microstructure" usually refer to the grains, grain boundary, imperfections, and impurities. The structure in which individual atoms are ordered is known as crystal structure, while microstructure at dimensions smaller than those visible with optical microscopes is frequently referred to as nanostructure. Microstructure is a material's extremely small-scale structure that may be seen with an optical microscope at magnifications more than 25×. It is the structure of a material's prepared surface. By using a SEM (TESCAN VEGA 33LMU), the microstructure at three distinct areas (the Al layer, the interface, and the Al-Cu layer) was studied. XRD and EDAX were used to analyze the sample composition.

Picture shows the SEM images of (a) Al & (b) Cu Powder materials [48, 49].

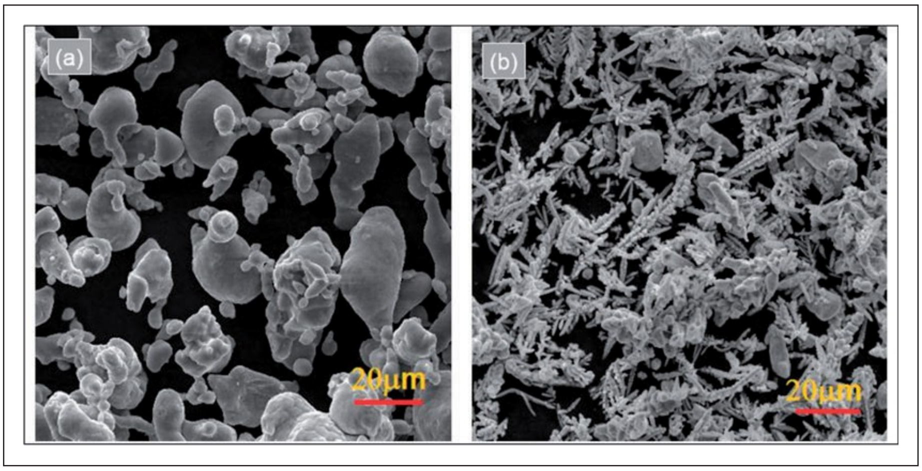


Fig. 2.4.2.1: Al & Cu SEM images

In these below figure, first figure, displays the Al-Cu alloy's annealed microstructure. The quantities of an Al-Cu solid solution phase () and an inter-metallic $CuAl_2$ phase () in this eutectic alloy were roughly equal. The phase is nearly white in fig., whereas the equi-axed linear intercept grain size was found to be around 8.0 um for both phases .The second figure enclosed that Al-Cu/Al two-layered composite samples' optical microstructures were at the interface area at different hot-pressed temperatures [49, 50].

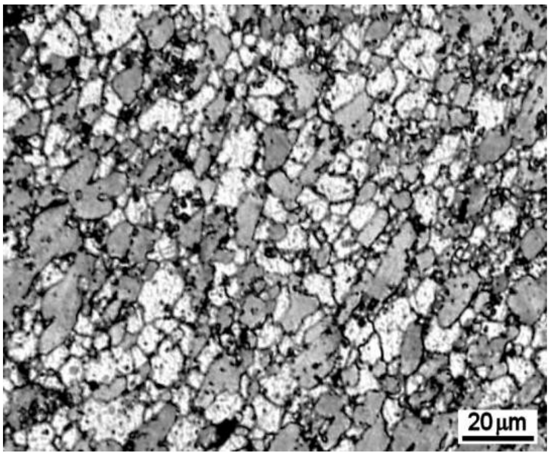


Fig. 2.4.2.2: Al-Cu composite in optical microscope

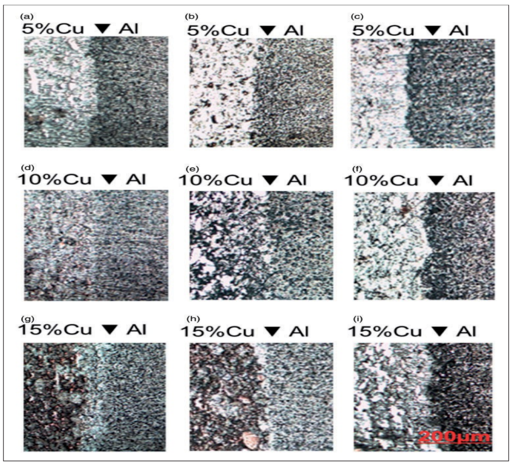


Fig. 2.4.2.3: Al-Cu composite (5 -15 wt%)

CHAPTER – 3

Research Gaps & Objectives

3.1. Research Gaps

The gaps which are observed from the literatures are:

Since the Al-Cu composite alloy's strength has increased, only few academics have used it for a variety of purposes. Additionally, because aluminum is a light material, these alloys are rarely used in industry.

Many qualities have been investigated, and in order to prepare a material for the creation of a Metal-Matrix Composite (MMC), some reduction techniques will also be employed. There is a limitation of literature on Al-Cu composite research and just a small number of researchers that focus on these areas.

3.2. Objectives of the present work

- The subsequent goals are suggested in the current thesis considering the existing literature review that is offered in this thesis and the pros and disadvantages of multiple articles that were collected. Development of Al-Cu alloy composites by Powder metallurgy (P/M) techniques at different weight percentages of Aluminium (Al) and Copper (Cu).
- Reduction of Copper oxide (CuO) with the help of dextrose material to produce Copper (Cu).
- Measurement of various physical and mechanical properties of developed Al-Cu Composites.
- Characterization of Al-Cu Composites via optical microscopy, FESEM, XRD analysis.
- Finally a comparative study has made based on the composite materials develop.

3.3. Chapter Summary

This part of the section offers literature on the various mechanical and physical properties of metal matrix composites that has been available for over a decade. The goal of the current activity is to fill the research gap mentioned above. The following section examines various methods for creating composite materials.

CHAPTER – 4

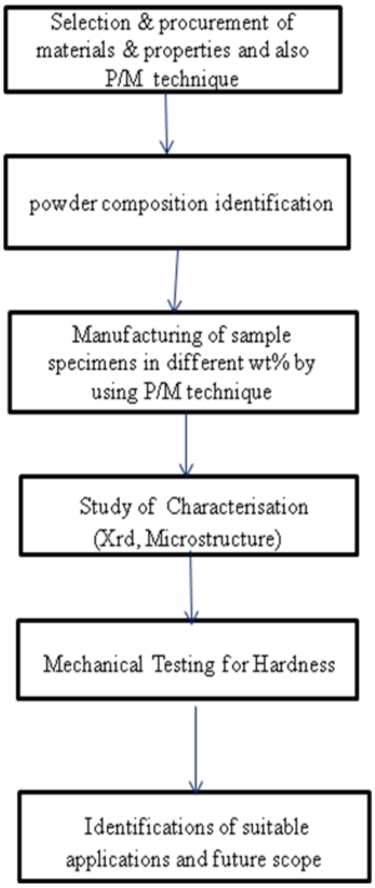
Methods & Methodology

This chapter comprehensively outlines the array of techniques and materials employed to accomplish the thesis work. Utilizing a variety of fabrication methodologies, it delves into the physical and mechanical attributes of selected materials (e.g., porosity, density, and hardness), alongside the characterization of materials (e.g., XRD, optical microscopy, and SEM) through meticulous experimental procedures.

The research project is being conducted using the following methodology.

4.1. Process Flow-

Flowchart demonstrating the methodical approach used in the current work :



4.2. Material selection

4.2.1. Matrix materials

For the development of Al-Cu composites, aluminum is used as its foundational matrix material. Known for their superb mechanical attributes, Al-Cu materials boast remarkable hardness and an impressive resistance to corrosion. Within the realm of aluminum, a complex web of varied properties and strict specifications appears, providing an enticing view of possible uses and developments. For this experiment, the development of Al-Cu composites and aluminum fine powder (98% extra pure) are used, which are provided by Loba Chemie Privet Limited. Some specifications of these powder materials are:

Table: 4.2.1.1: Pure aluminium specifications

Purity	98%	Grade	Extra Pure
Molecular Formula	A1	CAS No.	7429-90-5
H.S. Code	7603.101	Molecular Weight	26.98
Shelf Life	60 Months		

Table: 4.2.1.2: Pure aluminium physical properties

Physical state at 20 °C	Solid	Colour	Grey powder
Odour	Odorless	Melting point/ Freezing point [°C]	660.37 °C
Auto-ignition temperature [°C]	760 °C	Boiling point [°C]	2327°C
Density [g/cm3]	2.7	Solubility in water [% weight]	Insoluble in water

Table: 4.2.1.3: Pure aluminium technical properties

Appearance	*Gray powder*
Assay	*Min 98%*
Silicon (Si)	*Max 0.1%*
Copper (Cu)	*Max 0.02%*
Nitrogen content (as N)	*Max 0.001%*
Insoluble in dil. HCl	*Max 0.005%*
Iron (Fe)	*Max 0.1%*
Manganese (Mn)	*Max 0.02%*
Titanium (Ti)	*Max 0.03%*

4.2.2. Copper (Cu)

Copper is employed as a reinforcing material in the development of Al-Cu Composite materials. Excellent mechanical properties of copper powder include strength, durability, resistance to corrosion, thermal conductivity, and electrical conductivity. Loba Chemie Privet Limited provided electrolytic grade copper powder, which is 98% pure, for the Al-Cu composites manufacturing procedure used in the current research. Below are a few details about copper powder:

Table: 4.2.2.1: pure copper specifications

Grade	Electrolytic grade	CAS No.	7440-50-8
Purity	98%	Molecular Weight	63.55
Molecular Formula	Cu	Shelf Life	60 Months

Table: 4.2.2.2: Pure copper physical specifications

Physical state at 20 °C	Solid	Colour	Reddish Brown powder
Melting point/ Freezing point [°C]	1083°C	Density [g/cm3]	8.94
Boiling point [°C]	2595°C	Solubility in water [% weight]	Insoluble in water

Table: 4.2.2.3: Pure copper technical specifications

Appearance	Reddish brown powder
Copper (Cu)	Min 98.0%
Acid insoluble matter	Max 0.1%
Particle size	- 45 micron (Min 90%)

4.2.3. **Copper Oxide (CuO)**

Copper oxide (CuO) stands as a material of choice, prized for its cost-effectiveness and an array of exceptional chemical and physical properties. Sourced from the esteemed Loba Chemie Pvt. Ltd., renowned for its commitment to delivering extra-pure materials, CuO emerges as a stalwart contender in various applications. Here are some specifications highlighting the prowess of CuO material:

Purity: Exceptional levels of purity ensure optimal performance and reliability in diverse settings.

Chemical Stability: CuO exhibits robust chemical stability, making it ideal for enduring harsh environmental conditions and demanding industrial processes.

Thermal Conductivity: With commendable thermal conductivity, CuO excels in dissipating heat efficiently, facilitating enhanced thermal management solutions.

Electrical Properties: CuO showcases desirable electrical properties, making it a preferred choice for applications requiring excellent conductivity.

Optical Characteristics: Its optical properties contribute to its versatility, enabling applications in fields such as optoelectronics and photonics.

Particle Size Distribution: Precisely controlled particle size distribution ensures uniformity and consistency in various manufacturing processes.

Surface Area: The ample surface area of CuO material offers increased reactivity and efficiency in catalytic and surface-dependent applications.

Mechanical Strength: CuO exhibits impressive mechanical strength, enhancing its suitability for structural and functional purposes. These specifications underscore the multifaceted utility and reliability of CuO material, cementing its status as a cornerstone in scientific, industrial, and technological endeavors.

Table: 4.2.3.1: Copper oxide specifications

Grade	Extra Pure	**CAS No.**	1317-38-0
Purity	97%	**Molecular Weight**	79.55
Molecular Formula	CuO	**Shelf Life**	60 Months

Table: 4.2.3.2: Copper oxide physical specifications

Physical state at 20 °C	Solid	Colour	Black powder
Odour	Odorless	Solubility in water [% weight]	Insoluble in water
Density [g/cm3]	6.32		

Table: 4.2.3.3: Copper oxide technical specifications

Appearance	Black coloured fine powder
Assay	Min. 97%
Sulphate (SO4)	Max. 0.06%
Iron (Fe)	Max. 0.1%

4.2.4. **Dextrose**

Dextrose, a versatile material employed in metal treatment and recovery applications, assumes a pivotal role as a reducing agent in various experimental processes, facilitating the conversion of CuO to elemental copper (Cu). Dextrose possesses inherent reducing properties, enabling it to effectively participate in chemical reactions where reduction is required, such as the conversion of CuO to Cu. Widely available in various forms, dextrose is easily accessible for laboratory experiments and industrial applications alike, ensuring convenience in procurement and usage. In this experiment, dextrose material is provided from Sisco Research Laboratory (SRL) Pvt. Ltd. Here are some fundamental features of dextrose:

Table: 4.2.4.1: Dextrose specifications

Purity	Extra Pure AR	Molecular Weight	180.16
Molecular Formula	$C_6H_{12}O_6$	Shelf Life	60 Months

Table: 4.2.4.2: Dextrose technical specifications

Appearance (Colour)	White
Appearance (Form)	Crystalline powder
Solubility (Turbidity) 10% aq. solution	Clear
Solubility (Colour) 10% aq. solution	Colourless
Specific rotation [α]	+52.5° to + 53.0° (C=10, Water)
pH (10% aq.soln)	Min 5.0
Loss on drying	max. 0.2%
Chloride (CI)	max.0.0025%
Iron (Fe)	max. 0.0001%
Heavy Metals (Pb)	max. 0.0001%
Sulphate & sulphite (SO4)	max.0.005%

4.3. Experimental Methods

4.3.1. Reduction Process

High-purity copper oxide (CuO) powders sourced from Loba Chemie Pvt. Ltd. were utilized in the experimental setup. In this procedure, 1 gm of pure copper oxide was meticulously blended with 0.565 grams of exceptionally extra pure dextrose obtained from SRL Pvt. Ltd. The meticulous mixing of these powders preceded the initiation of reactions at approximately 650°C, facilitated within an inert atmosphere where nitrogen (N_2) gas was introduced. Remarkably, these reactions manifested within a brief timeframe of merely 12 to 15 minutes prior to the commencement of the experimental phase.

The primary reactions that ensued were as follows:

Dextrose ($C_6H_{12}O_6$) undergoes thermal decomposition to yield carbon (C) and water vapor (H_2O), leading ultimately to the formation of carbon monoxide (CO) and hydrogen gas (H_2).

$$C_6H_{12}O_6 \Rightarrow 6C + 6H_2O \Rightarrow 6CO + 6H_2$$

$$CuO + H_2 \Rightarrow Cu + H_2O$$

The copper oxide (CuO) engaged in a direct reduction reaction with hydrogen gas (H2), yielding elemental copper (Cu) and water vapor (H2O).

In summary, through meticulous preparation and controlled conditions, the experimental setup induced these significant chemical transformations, elucidating the intricate interplay between copper oxide and dextrose under elevated temperatures and inert atmospheres.

4.3.2. Synthesis of Al-Cu composite

Method-1

In these experimental procedures, commercially sourced pure aluminum powders were selected as the primary material. To attain uniformity, the loose aluminum powders underwent an extensive blending process, meticulously executed with a mortar over a duration spanning 2 to 3 hours. This thorough blending procedure ensured the consistent distribution of particles, laying the groundwork for uniform properties in the ensuing composite material. Following this meticulous blending phase, attention turned to commercially available pure copper powders, characterized by varying weight percentages (5 wt%, 10 wt%, 15 wt%, and 20 wt%). Each variation of copper powder underwent a careful mixing regimen, with one-hour intervals between each blending session to guarantee comprehensive homogenization. This methodical approach was essential to ensuring the even dispersion of copper particles throughout the mixture, facilitating the desired characteristics in the resulting composite. Once the powders were thoroughly mixed, they were delicately transferred into a cylindrical die chamber. Prior to this, it was imperative to meticulously clean the die to eliminate any extraneous particles that could compromise the integrity of the composite. Additionally, a measured amount of graphite powder was introduced into the die before compacting the sample. This step served the dual purpose of smoothing the surface and providing lubrication during the compaction process.

Utilizing a compaction machine with a precisely calibrated setup, the powders were subjected to compression at a pressure nearing 4 T. This controlled compaction process was pivotal, representing a critical stage in the experimental process.

By subjecting the blended powders to controlled compression, we were able to achieve solid cylindrical samples, hereby designated as Al-Cu composites. This outcome signifies the culmination of our experimental endeavor, marking the successful transformation of raw materials into a cohesive and structurally sound composite material.

Method-2

In these experimental procedures, we employed commercially procured pure aluminum powders as the fundamental material. These aluminum powders underwent a meticulous blending process in a mortar, meticulously conducted to complete homogeneity. This blending step is critical to ensure uniform distribution of particles throughout the mixture, which is vital for achieving consistent properties in the final composite material.

Following the blending process, we introduced reduced copper powder into the mixture. This copper powder was obtained through a reduction process facilitated by dextrose material, ensuring its purity and desired characteristics. Careful incorporation of the reduced copper powder into the blend of pure aluminum powder followed, with further blending in the mortar to achieve thorough integration. This step is crucial as it introduces copper, which can impart specific properties such as enhanced strength or conductivity to the composite material.

Subsequently, the meticulously blended powders were transferred into a solid cylindrical die chamber. The purpose of this transfer was to prepare for the compaction process, which involves applying pressure (approx. 4T) to the powder material to form a solid shape. The choice of a cylindrical die chamber is deliberate, as it allows for uniform compaction and the production of cylindrical or rod-like shapes, depending on the desired final product.

Before initiating the compaction process, utmost care was taken to clean the die thoroughly. Any presence of extraneous materials or particles could compromise the integrity and quality of the resulting composite. Therefore, meticulous cleaning procedures were implemented to ensure the absence of contaminants.

Furthermore, a small quantity of graphite powder was introduced into the die chamber alongside the blended aluminum-copper mixture. Graphite powder serves a crucial role in facilitating the compaction process. It acts as a lubricant, reducing friction between the powder particles and the walls of the die, thus aiding in the formation of a compacted, solid shape. Additionally, the presence of graphite powder can enhance the surface finish of the final product, contributing to its aesthetic appeal and functional properties.

In summary, the described process underscores the meticulous attention to detail and precision required in the production of composite materials. Each step, from blending and incorporation of additives to die cleaning and powder compaction, is carefully orchestrated to ensure the quality, integrity, and desired properties of the resulting composite material.

4.3.3. Sintering

Following the completion of the compaction procedures and the initial property measurements, such as porosity and density assessment, all the solid cylindrical samples (Al-5wt%Cu, Al-10wt% Cu, Al-15wt% Cu, Al-20 wt% Cu) were transferred into the tube furnace for further processing. Before the samples entered the tube furnace, thorough checks were conducted to ensure the proper functioning of temperature control switches, voltage regulators, and current control switches. Additionally, meticulous inspection of the inlet and outlet pipes of the temperature-controlled tube furnace was imperative.

Once all systems were confirmed to be in working order, the solid cylindrical samples were carefully placed into the tube furnace, and the temperature was set to approximately 620 °C under an inert atmosphere. The samples were then allowed to dwell at this temperature for duration of around 1 hour and 30 minutes. During this time, a small amount of nitrogen gas was continuously passed through the tube furnace to maintain an inert atmosphere, ensuring that no additional gases or air infiltrated the chamber.

Upon completion of the processing cycle, the furnace was switched off, and the samples remained within the furnace until the temperature subsided to ambient levels. This precaution prevented any thermal shock to the samples before they were removed from the furnace. Once the furnace had cooled down sufficiently, the samples were carefully extracted and prepared for further processing steps. Sintering furnace and its whole process is shown below.

Fig. 4.3.3.1 : Electric Muffle Furnace

Some specifications of furnace are given in table:

Table: 4.3.3.1: Technical specifications of Electric Muffle Furnace

Name	Electric Muffle Furnace – Tube Type	Area	75x75x1500 mm
Make	Naskar Electrical Equipments	Maximum operating Temperature	850°C
Voltage	230V/ Single phase 50Hz/3.5 kW		

4.3.4. Aging

Once all the measurable procedures had been completed, the solid cylindrical samples underwent further processing in the tube furnace to complete the aging behavior assessment of the Al-Cu composite. All the sintered Al-Cu samples (Al-5%Cu, Al-10wt% Cu, Al-15wt% Cu, Al-20 wt% Cu) were subjected to a heat treatment, followed by an aging process conducted at temperatures ranging between 190 and 200°C. The aging duration was set to 4 hours to allow for sufficient time for the desired material transformations to occur.

During the heat treatment process, the samples were exposed to controlled temperatures within the specified range to induce structural changes and enhance certain material properties. Subsequently, the aging phase commenced, during which the samples were maintained at the predetermined temperature for the specified duration.

This aging treatment is crucial for understanding the evolution of the material's microstructure and mechanical properties over time. By subjecting the samples to controlled heat and aging conditions, researchers can assess the stability, strength, and other key characteristics of the Al-Cu composite under realistic operating conditions. The aging behavior assessment provides valuable insights into the long-term performance and durability of the composite material, informing further optimization efforts and potential applications in various industries.

The whole aging process was given in these below furnace which was shown below.

Fig.4.3.4.1: Electric Pit Furnace

Some specifications of furnace are given in table:

Table: 4.3.4.1: Technical specifications of Electric Pit Furnace

Name	Electric Pit Furnace – Temperature Controlled	Area	75x75x300 mm
Make	Multispan	Maximum operating Temperature	1000°C
Voltage	230V/ Single phase 50Hz/3.5 kW		

4.4. Determination of mechanical property

The mechanical properties of a material encompass its response to an externally applied force. These properties play a pivotal role in categorizing and understanding the behavior of the material. Among the plethora of mechanical attributes, hardness, strength, ductility, and toughness stand out as the most commonly assessed. It's important to recognize that these mechanical properties are not fixed values; instead, they dynamically shift depending on factors such as temperature, loading rate, and environmental conditions. Hence, a series of rigorous tests are carried out under diverse conditions to accurately ascertain and analyze the values and behaviors of these properties.

4.4.1. Density

Apparent Powder Density measurement

In this procedure, we begin by selecting loose powders consisting of aluminum and copper in varying weight percentages. These powders are precisely weighed using a digital weighing machine and thoroughly mixed in a porcelain bowl to ensure homogeneity. Subsequently, the blended specimen is transferred into a cylindrical container to determine its volume. To reduce the porosity between the powder particles and enhance particle density, the cylinder is vigorously shaken multiple times.

Next, the diameter of the cylinder is measured using a Vernier Caliper, while the height of the powder sample is determined with the aid of a scale. This meticulous measurement process ensures accurate characterization of the specimen's dimensions, facilitating further analysis and experimentation.

Apparent Compact Density measurement

Following the completion of the compaction procedures, the sample is carefully removed from the apparatus. Subsequently, precise measurements are conducted to characterize the compacted sample. Utilizing a Vernier Caliper, the diameter of the compacted sample is meticulously determined, along with the measurement of its height. These comprehensive measurements are essential for accurately assessing the density of each compacted sample.

To calculate the volume of the compacted samples, the following formula is applied: $V = \pi d^2 h/4$, where V represents volume, d signifies diameter, and h denotes height. By applying this formula, the volume of each compacted sample is computed, enabling further analysis.

Moreover, the compacted density of the samples is determined using the formula: where $\rho = (m/v)$ represents density, m denotes mass, and v signifies volume. This calculation provides crucial insights into the density characteristics of the compacted samples, aiding in the interpretation of experimental results.

Apparent Sintered Density measurement

Following the completion of the sintering procedures, the sample is carefully removed from the apparatus. Subsequently, precise measurements are conducted to characterize the sintered sample. Utilizing a Vernier Caliper, the diameter of the sintered sample is meticulously determined, along with the measurement of its height. These comprehensive measurements are essential for accurately assessing the density of each sintered sample.

To calculate the volume of the sintered samples, the following formula is applied: $V = \pi d^2 h/4$, where V represents volume, d signifies diameter, and h denotes height. By applying this formula, the volume of each sintered sample is computed, enabling further analysis.

Moreover, the sintered density of the samples is determined using the formula: where $\rho = (m/v)$ represents density, m denotes mass, and v signifies volume. This calculation provides crucial insights into the density characteristics of the sintered samples, aiding in the interpretation of experimental results.

4.4.2. Porosity

Apparent Compact Porosity measurement

The apparent compact porosity, which assesses the interconnected pores and determines the permeability for gases and fluids to seep through the component, is determined through a specific method. Initially, the dry weight (W_d) of the sample is measured, followed by suspending it in water to obtain the suspended weight (W_s), and then reweighing it after removal from water to determine the wetty weight (W_w).

In this procedure, the first step involves measuring the dry weight (W_d) of the sample. Subsequently, the test specimens are submerged in water and boiled for 2 hours, ensuring they remain completely covered without contacting the heated bottom of the container. After the boiling period, the specimens are cooled to room temperature while still submerged. Following this, the specimens are suspended using a loop or halter of copper wire hung from one arm of a balanced scale. The balance is pre-counterbalanced with the wire in place and immersed in water to the same depth as during the specimen placement. The submerged weight of the specimen is then accurately measured using a weighing machine, with the weight of the beaker and water already known. For each test specimen, the suspended weight is recorded after the boiling process. After a 30-minute immersion in water, the specimens are removed, dried with tissue paper to eliminate surface water, and then digitally weighed to obtain the wet weight (Ww).

In The apparent compact porosity of the sample is as expressed by the relationship, which is shown below.

$P, \% = [(W_w - W_d) / (W_w - W_s)]$

Apparent Sintered Porosity measurement

Upon the completion of the sintering process, the apparent sintered porosity, which evaluates the interconnected pores and dictates the permeability for gases and fluids to permeate the component, is determined using a specific procedure. Initially, the dry weight (W_d) of the sample is gauged, followed by immersing it in water to acquire the suspended weight (W_s), and subsequently, reweighing it after extraction from water to ascertain the wet weight (W_w).

In this method, the initial step entails measuring the dry weight (W_d) of the sample. Following this, the test specimens are submerged in water and suspended using a loop or halter of copper wire hung from one arm of a balanced scale. The balance is pre-counterbalanced with the wire in position and immersed in water to the same depth as during specimen placement. The submerged weight of the specimen is then precisely measured using a weighing machine, with the weight of the beaker and water already established. For each test specimen, the suspended weight is documented. Following a 30-minute immersion in water, the specimens are withdrawn, dried with tissue paper to eliminate surface moisture, and subsequently digitally weighed to determine the wet weight (W_w).

In The apparent sintered porosity of the sample is as expressed by the relationship, which is shown below.

$P, \% = [(W_w - W_d) / (W_w - W_s)]$

4.4.3. Hardness measurement

Hardness, as a fundamental property of materials, typically denotes their resistance to deformation. Specifically, in metals, hardness reflects their capacity to withstand permanent or plastic deformation. In the realm of material testing, hardness often refers to the ability to resist indentation.

The Vickers hardness test, a widely used method, employs a square-base diamond pyramid as the indenter. This pyramid features an included angle of 136° between the opposite faces. The resulting diamond-pyramid hardness number (DPH), also known as the Vickers hardness number (VHN or VPH), is determined by dividing the applied load by the surface area of the indentation. In practical terms, this area is derived from microscopic measurements of the diagonals of the impression. The DPH can be calculated using the formula:

$DPH = 1.854P/L^2$

Where, P = applied load, kg

L = average length of diagonals, mm

θ = angle between opposite faces of diamond =136°.

Following the completion of microstructure observation, macro-Vickers hardness & micro Vickers hardness testing is conducted. For Al-Cu composites, a load of 5 Kgf is applied during the macro-Vickers hardness test, utilizing a brale indenter and for micro-Vickers hardness test 25gf load is applied and dwell time is 15 sec. Three readings are taken for each composition of the sample, and the average values are carefully considered for analysis. These two machines are shown below, which were used for the experiment. This meticulous approach ensures accurate assessment and characterization of the material's hardness properties.

(a) Macro-Vickers Hardness Testing Machine	(b) Micro-Vickers Hardness Testing Machine

Fig. 4.4.3.1: Hardness Testing Machine

4.5. Characterization behavior

Materials characterization is a crucial process within materials engineering, involving the comprehensive study and understanding of the physical, electrical, & chemical properties of various substances. This analysis aids in pinpointing the most suitable materials for specific applications, thereby facilitating informed decisions in product design and development. Numerous techniques, such as spectroscopy and microscopy, are used in the methodologies used in materials characterization. With the use of microscopy, materials can be examined at the atomic and microscopic levels to reveal details about their composition and structure. Spectroscopy, on the other hand, provides important information on the chemical and molecular characteristics of matter by assessing its interaction with light. Characterizing materials has several uses, from determining the characteristics of raw materials to keeping an eye on quality during production and processing. It is also essential for assessing how well materials function in a variety of applications. One important characterization technique is Scanning Electron Microscopy (SEM), which uses an electron beam to scan a material sample's surface in order to provide thorough viewing and analysis. Moreover, X-ray diffraction is used to ascertain the composition and crystal structure of materials, while spectroscopy helps to investigate the chemical and molecular characteristics of materials.

4.5.1. XRD

A non-destructive technique called X-ray diffraction analysis (XRD) can reveal intricate details about a material's chemical composition, crystal structure, and physical properties. It is dependent on the occurrence of constructive interference between a crystalline sample and monochromatic X-rays. Shorter wavelength electromagnetic radiation or X-rays, are created when electrically charged particles accelerate to a high enough degree. The produced X-rays are precisely targeted and directed towards a sample of materials during XRD. Diffracted rays are produced when these incident rays interact with the sample; these rays are then detected, processed, and counted. A diffraction pattern is produced by plotting the intensity of these diffracted rays, which are scattered by the material at different angles. This pattern provides important details regarding the atomic arrangement of the substance. This pattern provides important details regarding the atomic arrangement of the substance. Atoms inside the crystal structure deflect X-rays, which causes diffraction to happen. Away from the crystal, these dispersed rays reinforce one another in particular directions. Bragg's law describes the quantitative relationship between this reinforcement and the distance between atomic planes. The condition of Bragg's law $n\lambda = 2d \sin \theta$, being met is diffraction.

Understanding the characteristics of nanoparticles and determining the phases that are present in the material depend heavily on the peaks that are seen in the XRD pattern. Sharp peaks imply larger crystallites, whereas broad peaks suggest smaller ones. The breadth of these peaks represents the average size of the crystalline particles. This data facilitates the characterization of the material's structure and the evaluation of its appropriateness for different purposes.

4.5.2. Microstructure

4.5.2.1. Optical Microscope

Microstructure is the material's developed appearance as seen under a microscope at magnifications greater than 25×. It includes features including phase structures, grain patterns, and defects that may be present. Important components such as grains, crystal lattices, and phases are observed in the examination of metals. The temperature, pressure, cooling rate, alloy composition, and most importantly, heat treatment, are some of the key elements that shape the microstructure of the metal. Predicting material attributes such as toughness, conductivity, corrosion resistance, hardness, ductility, and conductivity requires a deep understanding of microstructure.

In the field of materials science, analysis of microstructure is a vital technique. Through the use of methods like optical and scanning electron microscopy to examine the microstructure of various materials. In order to do this, goals including improving sample preparation techniques, performing metallographic polishing and etching to reveal microstructural features, and using digital photography for documentation are all necessary.

Following the completion of the sintering and aging processes in the experimental procedure, all samples undergo a meticulous sample preparation regimen in preparation for observation under an optical microscope. Initially, the samples undergo polishing using various grades of polishing paper to achieve the necessary surface smoothness. Subsequently, a cloth polishing machine (‘Leco Spectrum System 1000’) is employed to impart a refined appearance to the samples, ensuring the elimination of any scratches or abrasions. For the etching process, Keller’s reagent is indispensable. Comprising 2.5 ml of HNO_3, 1.5 ml of HCl, 1 ml of HF, and 95 ml of distilled water, this solution is meticulously prepared. Once prepared, the samples are subjected to etching, followed by drying, rendering them ready for examination under an optical microscope, specifically a “Leica DM 2700M” microscope, which is shown below.

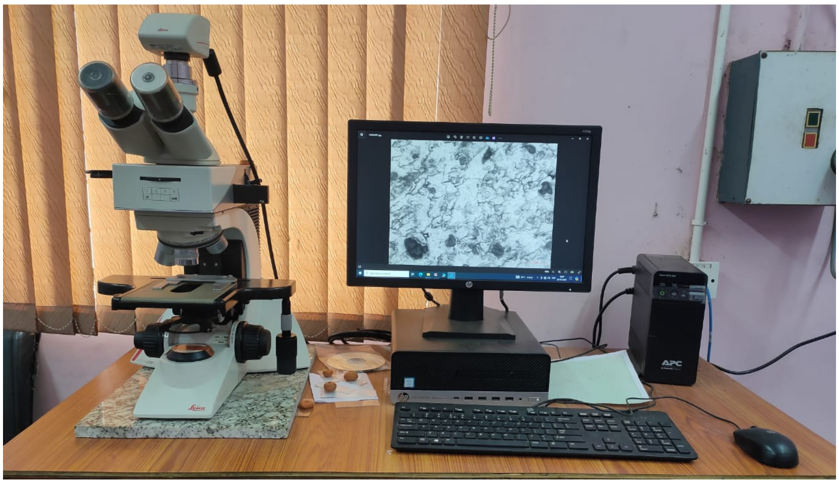


Fig. 4.5.2.1.1: Optical Microscope Image

4.5.2.2. FESEM Study

The beam of electrons that is focused and is used to scan a material to create images is known as a scanning electron microscope (SEM). When electrons contact with a material, they produce a variety of signals that can be picked up by electron microscope detectors, providing details about the sample's composition and surface topography. A new technique called Field Emission Scanning Electron Microscopy (FE-SEM) emerged as a result of the development of technology used in Scanning Electron Microscopy (SEM), a type of electron microscope, which allowed for the availability of higher resolution images. These types of microscopes function in a similar way to ordinary scanning electron microscopes (SEM). The specimen's surface is scanned by an electron beam focused by electromagnetic lenses, and the reflected and interacting electrons produce an image of the sample's topography and surface. A Field Emission Gun (FEG) serves as the electron source in FESEMs. Whereas thermionic emission is employed in SEM, a potential gradient is applied in FEGs to emit the electron beam.

The 'INSPECT F50' SEM was used in this experiment to examine the sample's morphology. This apparatus is frequently used for energy dispersive X-ray microanalysis-based high-resolution imaging and composition analysis. Images and composition data are generated by the machine using different SEM detectors. While the ETD detector records secondary electron pictures and topography, the Back Scattered Electron Detector (BSED) is utilized to display images and composition. Furthermore, EDX aids in the performance of chemical analysis.

For microstructural characterization studies in FESEM, the Al-5%Cu powder samples are thoroughly dried before being securely affixed to the sample holder using carbon tape. Subsequently, the samples are placed onto the carbon tape and subjected to gold coating via a sparter coater to facilitate imaging on non-metallic surfaces. The samples are then vacuumed under high vacuum conditions for approximately 10-15 minutes. Following this, the prepared samples are loaded onto the 'INSPECT F50' machine, with image generation being facilitated by controlling parameters such as probe current, emission current, and voltage.

Fig. 4.5.2.2.1: FESEM Machine Image

CHAPTER– 5

Results & Discussion

5.1. Reinforcement composition with heat treatment

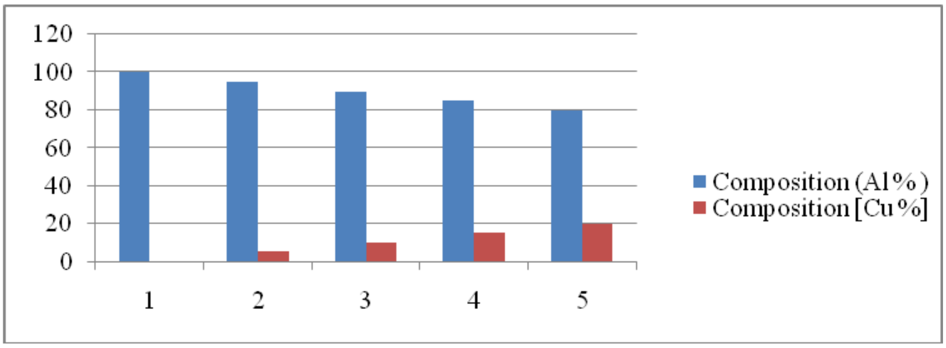


Fig. 5.1.1: Effect of copper content after heat treatment

These graphs represent the alloy compositions of the material, which is matrix is aluminium and reinforcement is copper and also the combinations of Al-Cu matrix with varying percentages. The composite shows the lean diffusion of the particulate material in the matrix. Increase the reinforcement concentrations enhance the hardness after heat treatment process.

5.2. XRD

X-ray diffraction stands as a cornerstone in material analysis, offering a comprehensive projection of its internal structure through which we can explore the complex composition of various substances. Through the utilization of Miller indices, this technique delves deep into the phase structure, unraveling the intricate spatial organization of atoms within the material. Each distinct peak observed in the diffraction pattern not only unveils the ever-changing weight percentages of constituents but also offers a nuanced portrayal of the crystal lattice configuration. Remarkably versatile, X-ray diffraction transcends the physical states of materials, proficiently deciphering the crystalline makeup of samples, whether in finely powdered or solid forms. Furthermore, its discerning prowess extends to distinguishing between the multifaceted polycrystalline phases present, thus further enriching our comprehension of the material's inherent composition and distinctive properties.

Figure Shows the X-ray diffraction pattern for Al-Cu composite and reduction of copper from copper oxide and the maximum intensity of diffraction peak at 2θ.

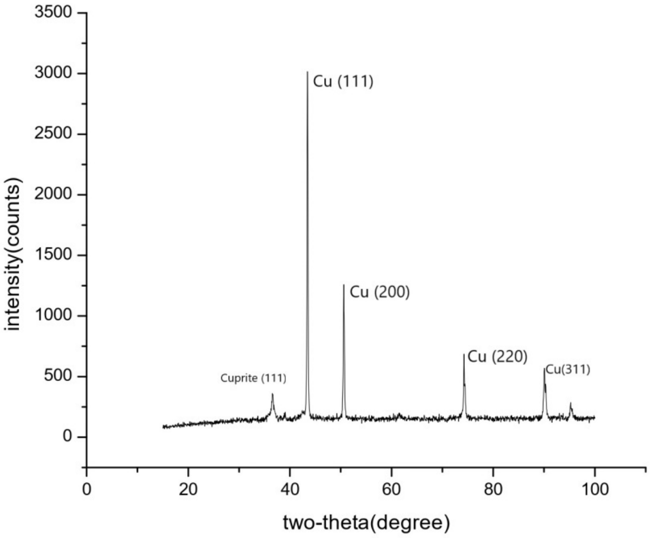


Fig. 5.2.1: X-ray Diffraction pattern of Copper from reduction of Copper oxide

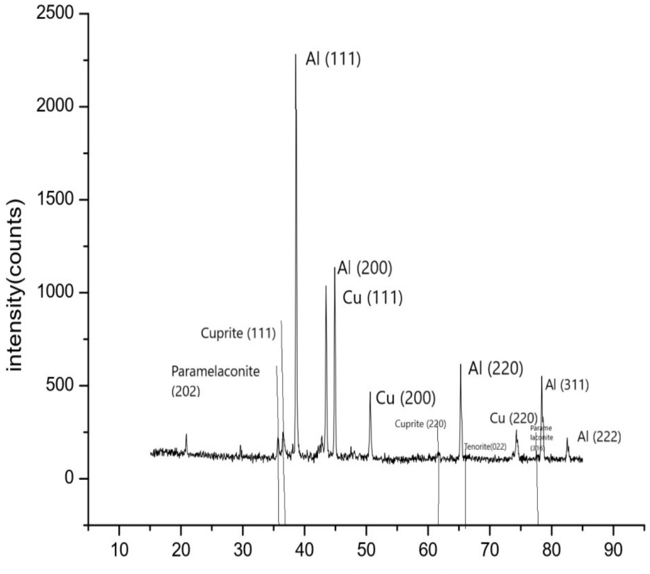


Fig. 5.2.2: X-ray Diffraction pattern of reduction Al-Cu composite, (Method-II)

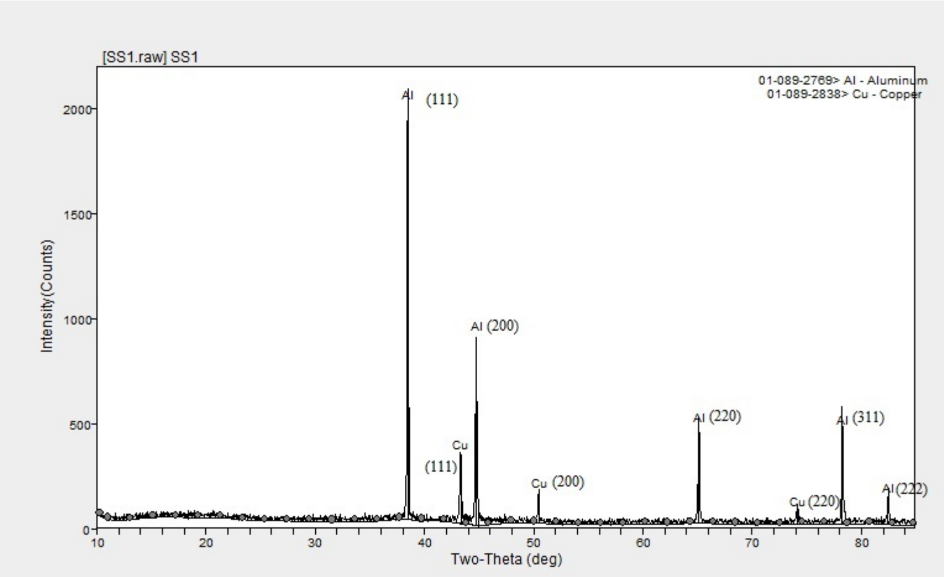


Fig. 5.2.3: X-ray Diffraction pattern direct Al-Cu composite, (Method-I)

In this series of experiments, the Al-Cu composites underwent comprehensive phase characterization employing a Ultima III Rigaku X-Ray Diffractometer. In Figure 5.2.3, the phase analysis of conventionally sintered Al-Cu composites, as determined by XRD, unveils a heightened level of crystallinity, which is perceptible through the presence of sharp peaks. Upon scrutiny of the XRD peaks (refer to Figure 5.2.1), the presence of copper, derived from the reduction of copper oxide (CuO), is evident, alongside a minor occurrence of cuprite. The distinct, sharp peaks underscore the peak intensity of copper. Figure 5.2.2 depicts the discernible presence of both aluminum and copper in the XRD pattern, with copper originating from the reduction of copper oxide. The peak intensity of Al-Cu further validates the authenticity of the material within these phases.

The XRD pattern of the pressed composite samples with different Cu contents, processed at 630°C with pure aluminum acting as the matrix material, is shown in Figure 5.2.3. The material exhibits distinct phases of Al and Cu, both of which have exceptionally high diffraction intensities. The pure aluminum phases were found to have the highest intensity at a 2θ value of 38.482°, which corresponds to the (111) plane. There are also peaks at 44.736°, 65.106°, 78.250°, and 82.458° that are indicative of aluminum. The corresponding (hkl) planes for these peaks are (200), (220), (311), and (222), respectively. Copper, on the other hand, peaks at the highest intensity at a 2θ - value of 43.309°, which corresponds to the (111) plane. In the Al-Cu composites, there are additional copper-related peaks at 50.449° and 74.146°, corresponding to (hkl) planes of (200) and (220), respectively.

Similarly, at 650°C & inert atmosphere, the XRD pattern in Figure 5.2.1 shows the reduction of copper compounds from copper oxide. The (111) plane, with a 2θ value of 43.446°, exhibits the maximum copper intensity. Moreover, additional copper phases with equivalent (hkl) planes of (200), (220), and (311) are found for 2θ values of 50.586°, 74.245°, and 90.051°. Additionally, this XRD pattern shows evidence of Cuprite traces.

Like-wise, pure aluminum and reduced copper were seen in Figure 5.2.2's XRD pattern at about 630°C in an inert atmosphere. The graph of these XRD patterns shows that the (111) plane, or a 2θ value of 38.548°, is where pure aluminum exhibits the highest intensity. Other peaks with comparable planes of (200), (220), (311), and (222) are also detected at 44.802°, 65.191°, 78.304°, and 82.508°. Additionally, the XRD pattern shows that the (111) plane has the maximum intensity of copper with a 2θ value of 41.3°. A similar observation was made of further copper peaks at 50.537° and 74.198°, which correspond to planes (220) and (200), respectively. Additionally, from the XRD perspective, traces of paramelaconite, cuprite, and tenorite are detected, albeit with significantly lower intensities.

All the XRD analyses were conducted with the assistance of the JPCDS software and MDI/JADE7 software.

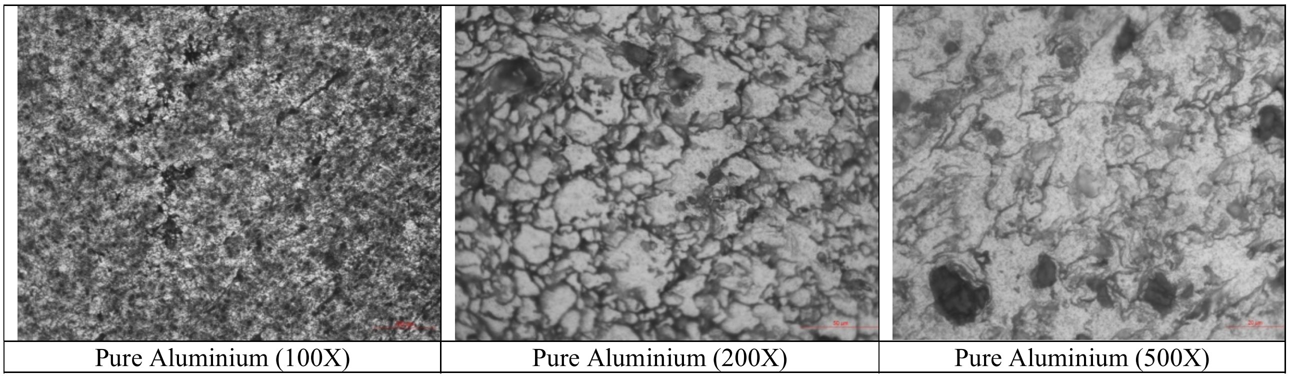
Table: 5.2.1: Copper (Cu) particle Size Calculation

Element	2θ (Degree)	θ in radian	Flex width	d - value	Particle size (Angstrom)
Cuprite (111)	36.55	0.3185	0.412	2.4564	3.36413
Copper (111)	43.45	0.37915	0.353	2.081	3.92643
Copper (200)	50.55	0.44115	0.353	1.8041	3.92646
Copper (220)	74.25	0.648	0.353	1.2762	3.92659
Copper (311)	90.05	0.786	0.412	1.0889	3.36439

5.3. Microstructure Study

5.3.1. Optical Microscope

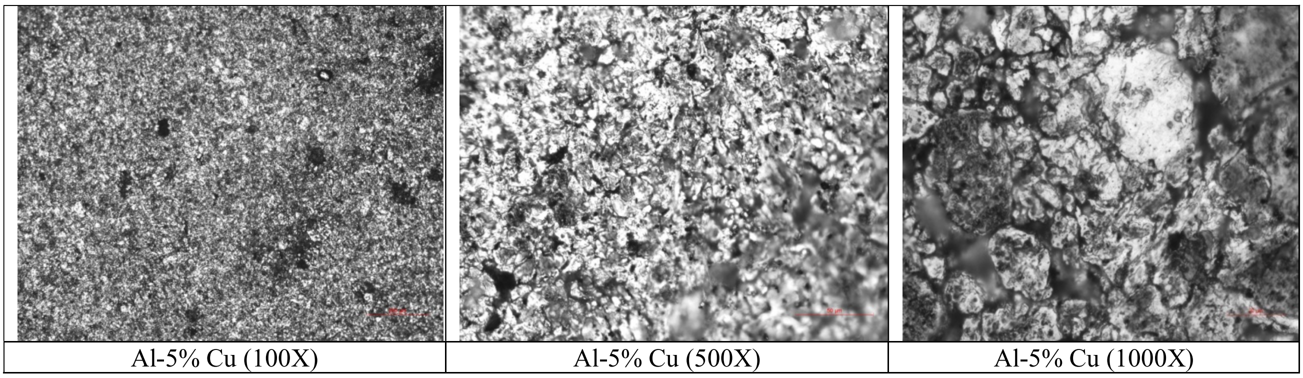
The microstructure of a pure aluminum sample, as observed under an optical microscope, is depicted in the figure below.



Pure Aluminium (100X)	Pure Aluminium (200X)	Pure Aluminium (500X)

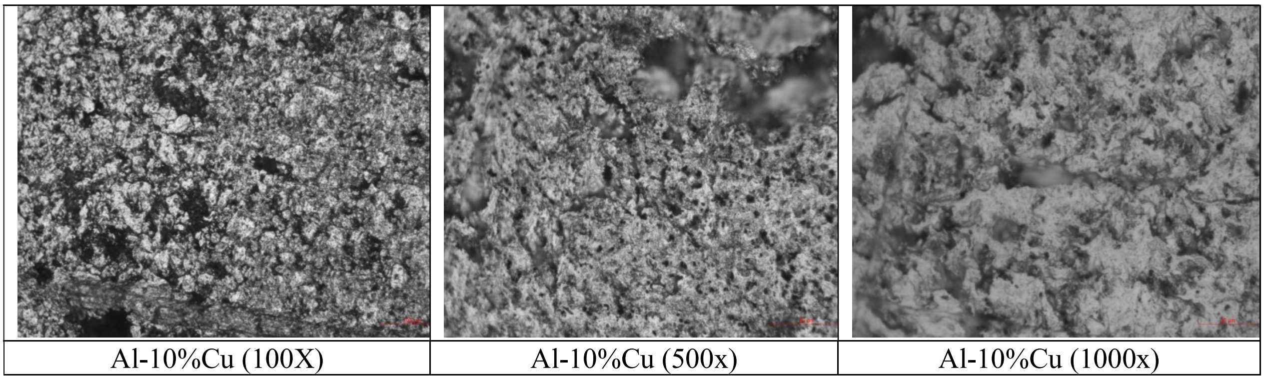
Fig. 5.3.1.1: Pure Alumnium structure in Optical Microscope images

The following picture depicts the microstructure as seen using an optical microscope for different compositions, such as 5%, 10%, 15%, and 20% reinforcement of copper (Al-5%Cu, Al-10%Cu, Al-15%Cu, and Al-20%Cu).



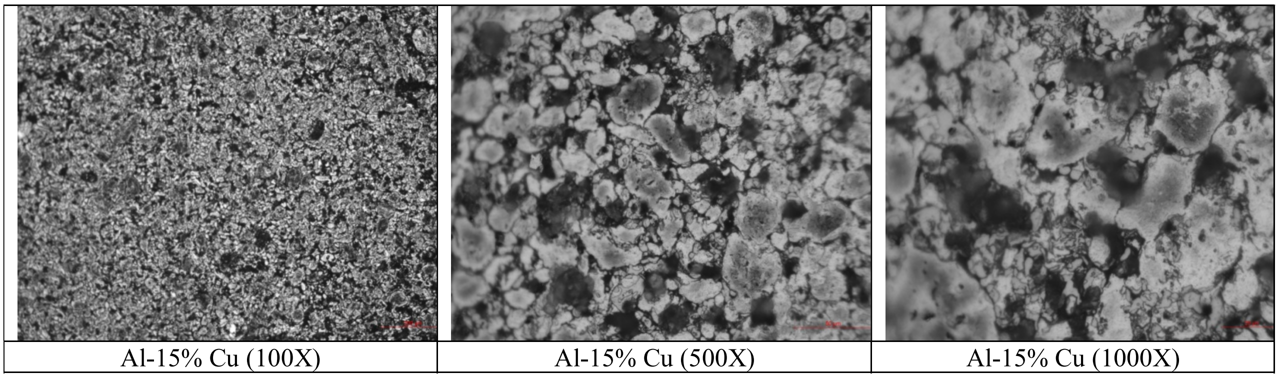
Al-5% Cu (100X)	Al-5% Cu (500X)	Al-5% Cu (1000X)

Fig. 5.3.1.2: Al-5%Cu Composite in optical microscope images, Method-I



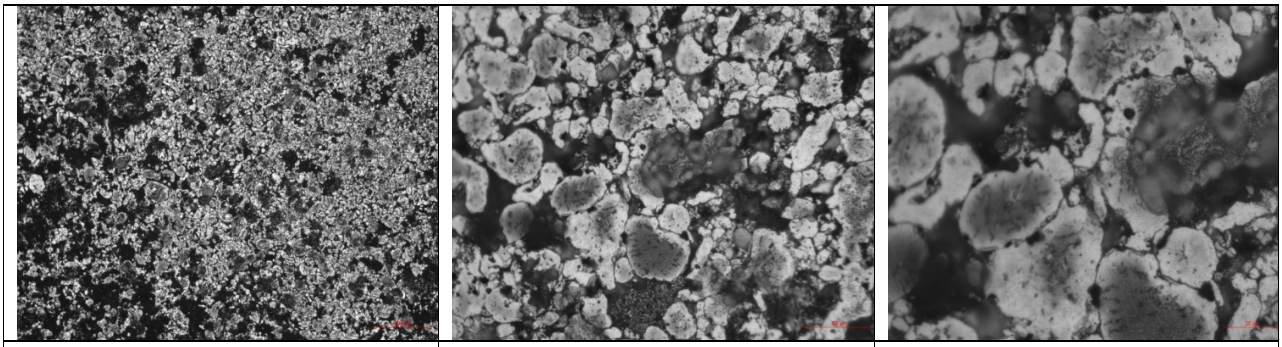
Al-10%Cu (100X)	Al-10%Cu (500x)	Al-10%Cu (1000x)

Fig. 5.3.1.3: Al-10%Cu Composite in optical microscope images, Method-I



Al-15% Cu (100X)	Al-15% Cu (500X)	Al-15% Cu (1000X)

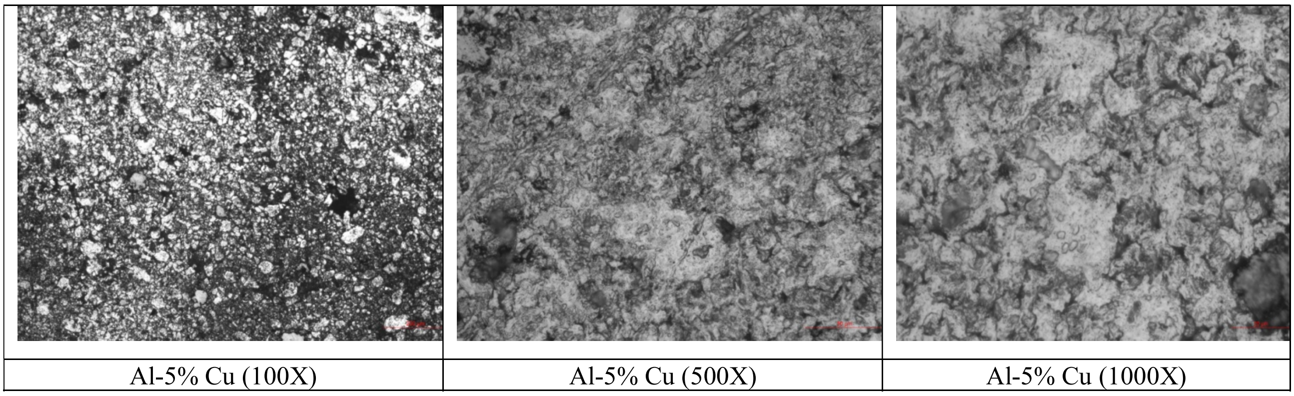
Fig. 5.3.1.4: Al-15%Cu Composite in optical microscope images, Method-I



Al-20% Cu (100X)	Al-20% Cu (500X)	Al-20% Cu (1000X)

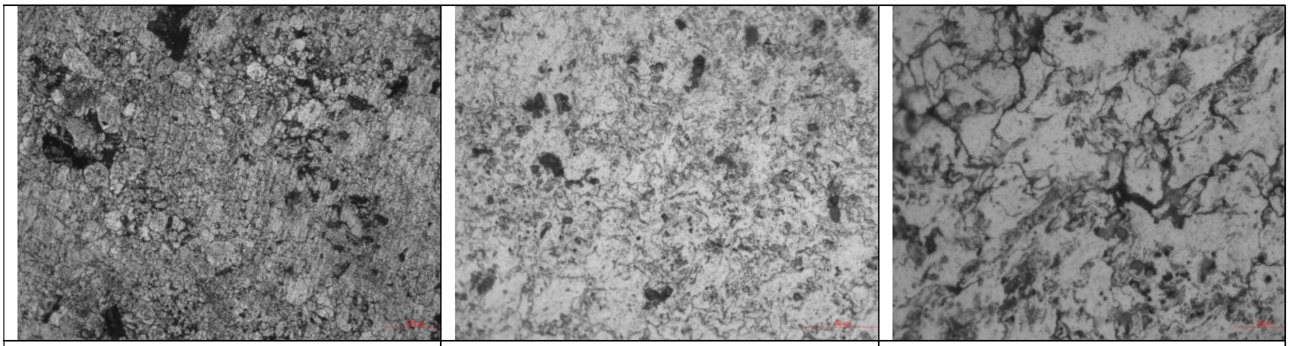
Fig. 5.3.1.5: Al-20%Cu Composite in optical microscope images, Method-I

Similarly, the microstructure of reduced Cu (Al-5%Cu, Al-10%Cu, Al-15%Cu, and Al-20%Cu) reinforced at different compositions 5%, 10%, 15%, and 20% is depicted in the figure below.



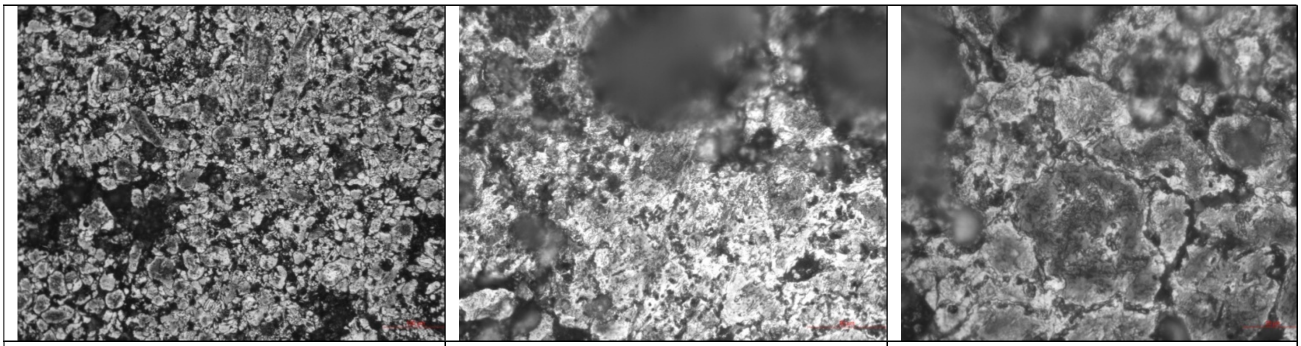
Al-5% Cu (100X) | Al-5% Cu (500X) | Al-5% Cu (1000X)

Fig. 5.3.1.6: Al-5%Cu Composite in optical microscope images, Method-II



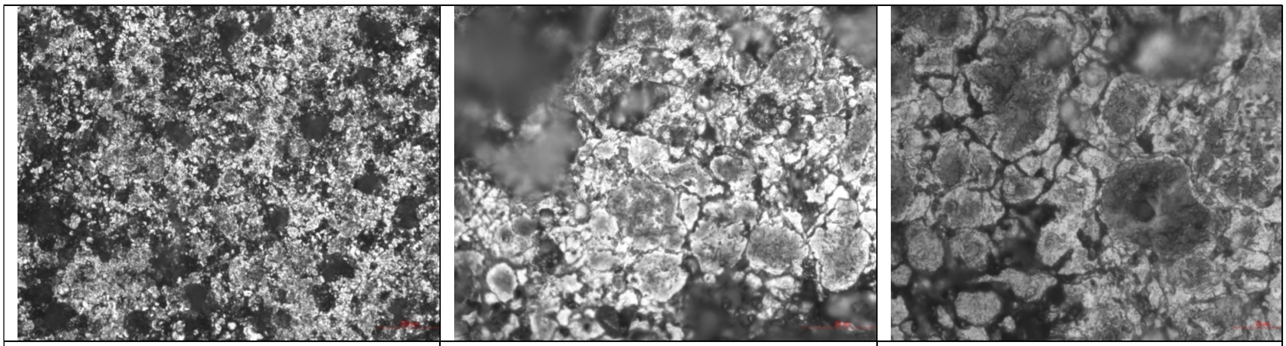
Al-10% Cu (100X) | Al-10% Cu (500X) | Al-10% Cu (1000X)

Fig. 5.3.1.7: Al-10%Cu Composite in optical microscope images, Method-II



Al-15% Cu (100X) | Al-15% Cu (500X) | Al-15% Cu (1000X)

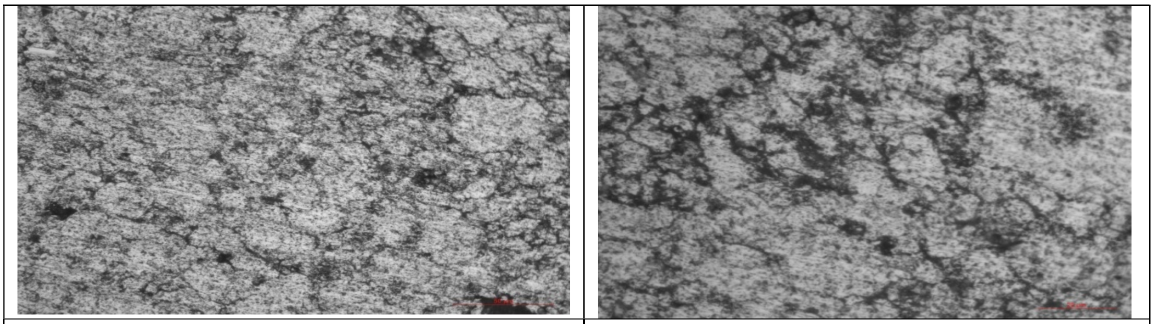
Fig. 5.3.1.8: Al-15%Cu Composite in optical microscope images, Method-II



Al-20% Cu (100X) | Al-20% Cu (500X) | Al-20% Cu (1000X)

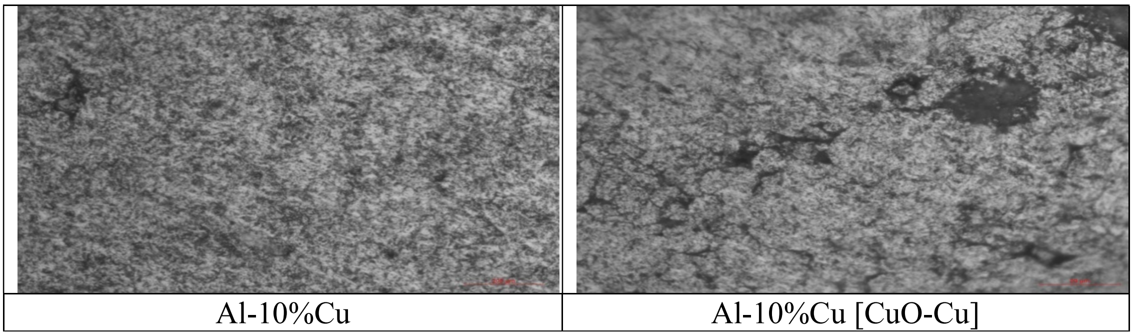
Fig. 5.3.1.9: Al-20%Cu Composite in optical microscope images, Method-II

Certainly, the microstructure observed through an optical microscope for various compositions, namely 5%, 10%, 15%, and 20% reinforcement of copper (Al-5%Cu, Al-10%Cu, Al-15%Cu, and Al-20%Cu), following the completion of the aging process, is depicted in the following image.



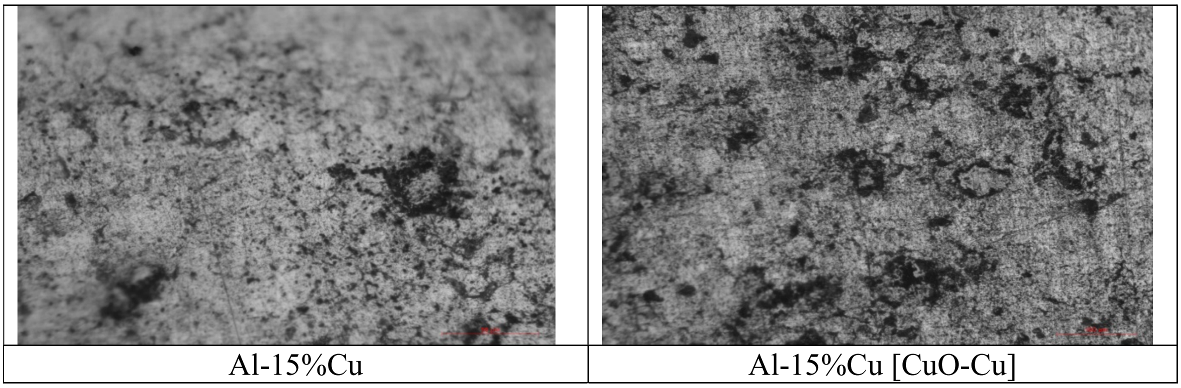
Al-5%Cu | Al-5%Cu [CuO-Cu]

Fig. 5.3.1.10: Al-5%Cu Composite in optical microscope images after aged



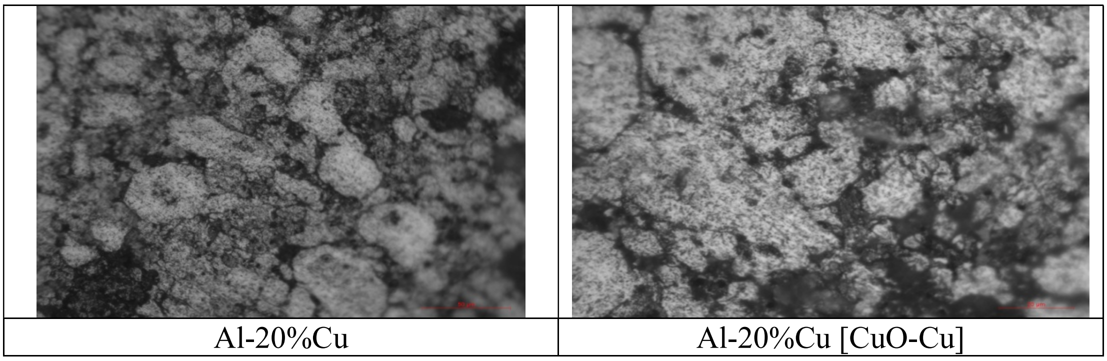
Al-10%Cu | Al-10%Cu [CuO-Cu]

Fig. 5.3.1.11: Al-10%Cu Composite in optical microscope images after aged



Al-15%Cu Al-15%Cu [CuO-Cu]

Fig.5.3.1.12: Al-15%Cu Composite in optical microscope images after aged



Al-20%Cu Al-20%Cu [CuO-Cu]

Fig.5.3.1.13: Al-20%Cu Composite in optical microscope images after aged

The material employs copper (Cu) as its reinforcement, exhibiting a distinct dark hue within these profiles. These conspicuous dark inclusions intricately map out the distribution of copper within the microstructure, while the gleaming white portions denote the aluminum matrix. Moreover, the given images reveal finely detailed grains also. Upon increasing the proportion of reinforcement from 0% to 20%, the microstructure undergoes a significant augmentation in the distribution of copper phases, accompanied by a notable surge in porosity levels. This evolution underscores the intricate interplay between reinforcement proportions and the resulting micro-structural characteristics, offering insights into the material's mechanical properties and performance.

5.3.2. FESEM

The microstructure of the aluminum-copper (Al-5%Cu) composite sample in FESEM is depicted in the following figure. Figures 5.3.2.1 provide an overview of the entire structure of the Al-5%Cu composite material, offering a comprehensive view of its intricate composition. In figures 5.3.2.2, the copper powder is prominently displayed, showcasing the reduction of CuO to dextrose and highlighting the transformation process. Moving on to figures 5.3.2.3, the cubic structure of these composite materials is clearly depicted, revealing the inherent structural integrity of the Al-5%Cu composition.

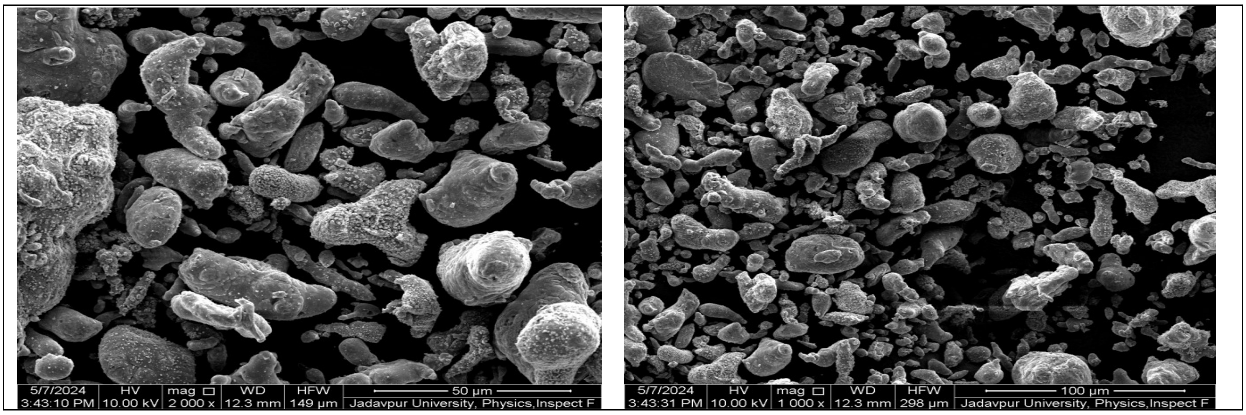


Fig. 5.3.2.1: Al-5%Cu composite whole images in FESEM

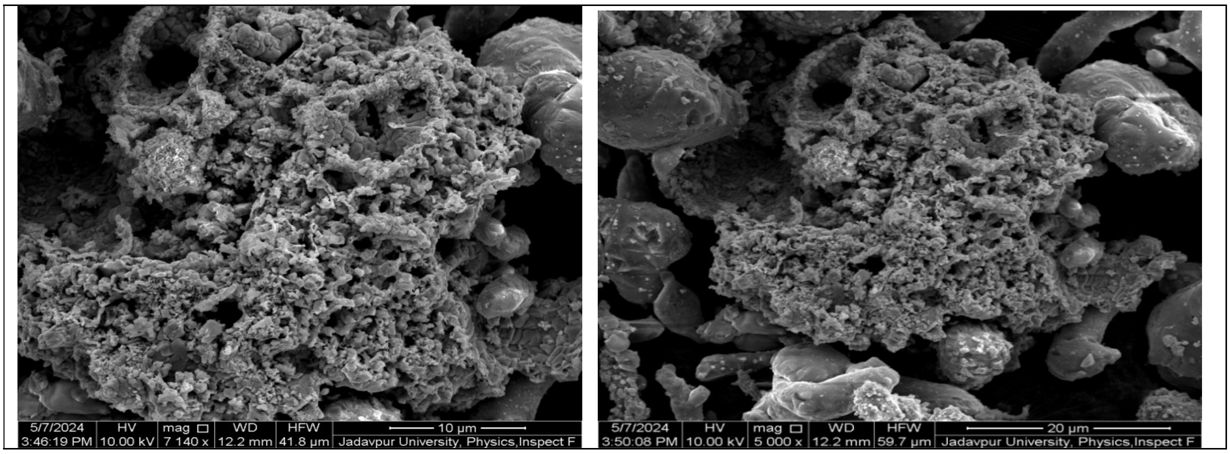


Fig.5.3.2.2: Copper structure in FESEM

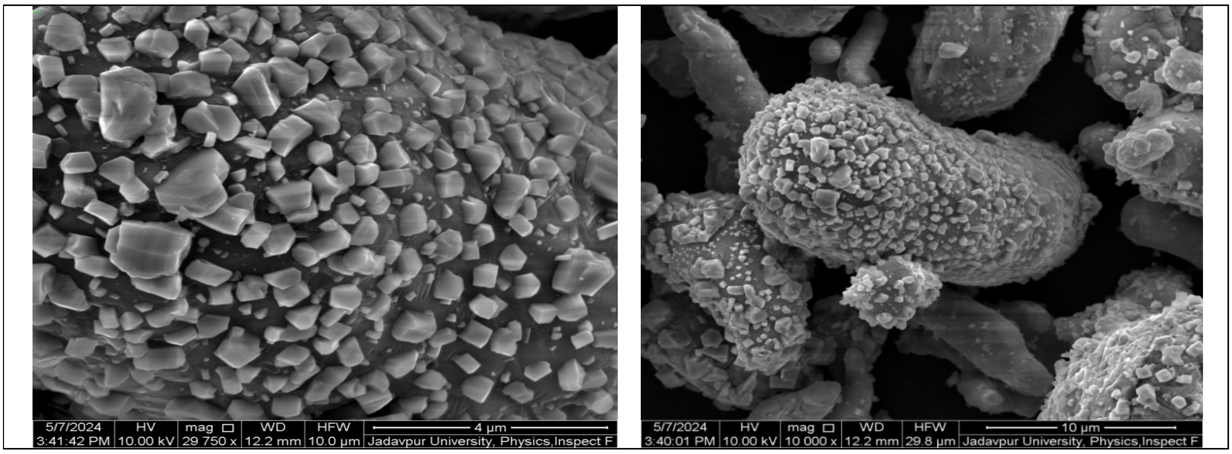


Fig. 5.3.2.3: Al-5%Cu cubic structure in FESEM images

5.4. **Hardness**

Aluminum-copper (Al-Cu) samples with varying weight percentages were subjected to the Macro-Vickers hardness test. The tables below show the corresponding hardness values. After examining the data, a distinct pattern became evident that hardness values increased noticeably and quickly as the percentage of reinforcement increase in all sample compositions.

Table 5.4.1: Macro -Vickers Hardness, Method- I

Macro-Vickers Hardness Test			
Sl. No.	Composition (Al % + Cu%)	Vickers Hardness Number (VHN) [Before Aged]	Vickers Hardness Number (VHN) [After Aged]
1	100 +0	HV 27.27	
2	95+5	HV 32.98	HV 34.86
3	90+10	HV 46.05	HV 51.64
4	85+15	HV 52.45	HV 53.39
5	80+20	HV 59.52	HV 61.57

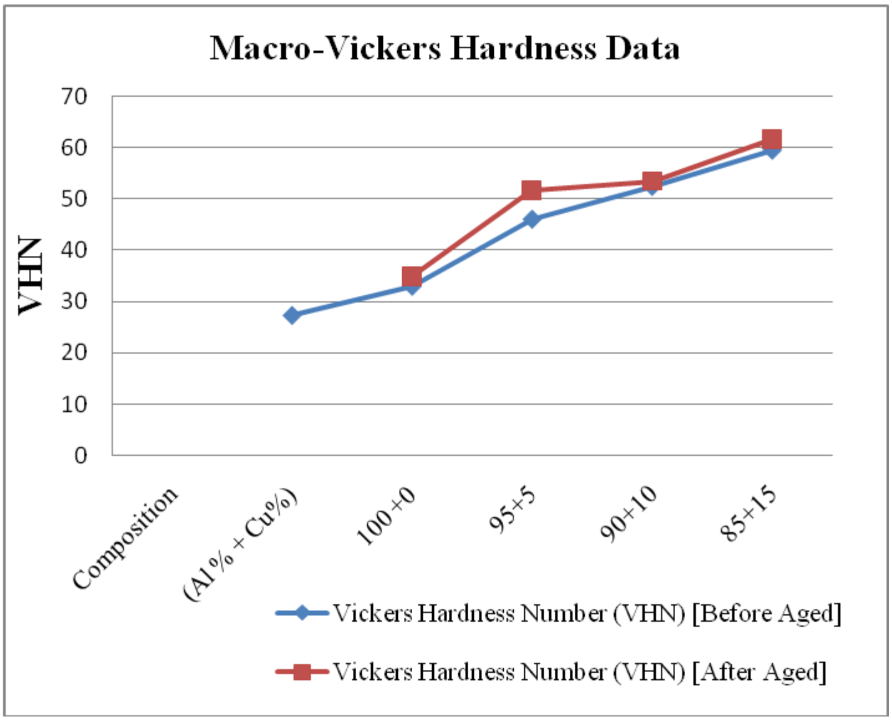


Fig.5.4.1.1: Macro-Vickers Hardness before and after aged samples graph, Method-I

Table 5.4.2: Micro-Vickers Hardness

Micro-Vickers Hardness Test		
Sl.No.	Composition (Al % + Cu%)	Vickers Hardness Number (VHN)
1	95+5	HV 65.83
2	90+10	HV 72.43
3	85+15	HV 76
4	80+20	HV 92.8

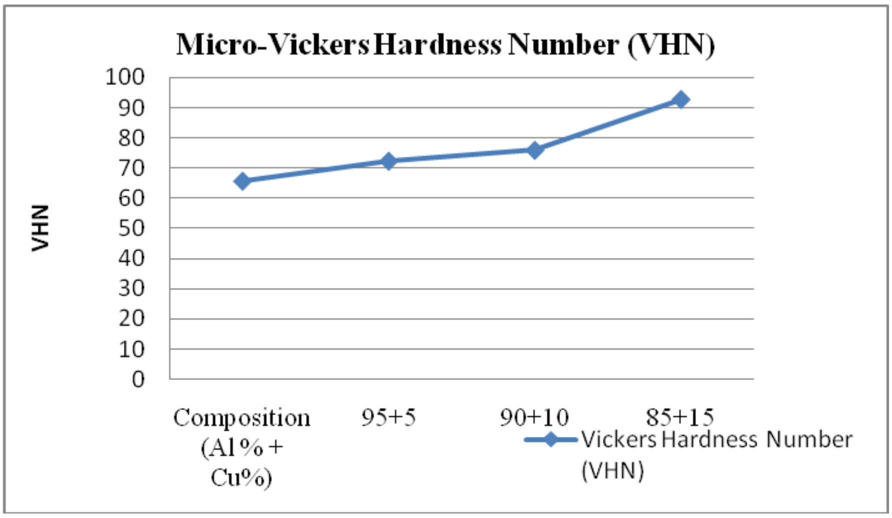


Fig.5.4.1.2: Micro Vickers hardness Al-Cu composites (5wt% - 20wt%) graph

Upon completion of the aging process, the hardness values of all samples were once again measured using a macro-Vickers hardness tester machine. It was noted that as the percentages of the reinforcement were increased, there was a corresponding increase in all measured values.

Similarly, samples of aluminum-copper (Al-Cu), where copper is obtained from reduction copper, were tested for hardness using the Macro-Vickers method at different weight percentages. The associated hardness values are displayed in the table 5.4.3. After analyzing the data, a clear pattern emerged, showing that in all sample compositions, hardness values rose markedly and rapidly as the quantity of reinforcement increased.

Table 5.4.3: Macro-Vickers Hardness, Method-II

Macro-Vickers Hardness Test			
Sl. No.	Composition (Al % + Cu%)	Vickers Hardness Number (VHN) [Before Aged]	Vickers Hardness Number (VHN) [After Aged]
1	95+5	HV 30.62	HV 34.9
2	90+10	HV 38.8	HV 52.2
3	85+15	HV 41.71	HV 53.87
4	80+20	HV 56.10	HV 55.28

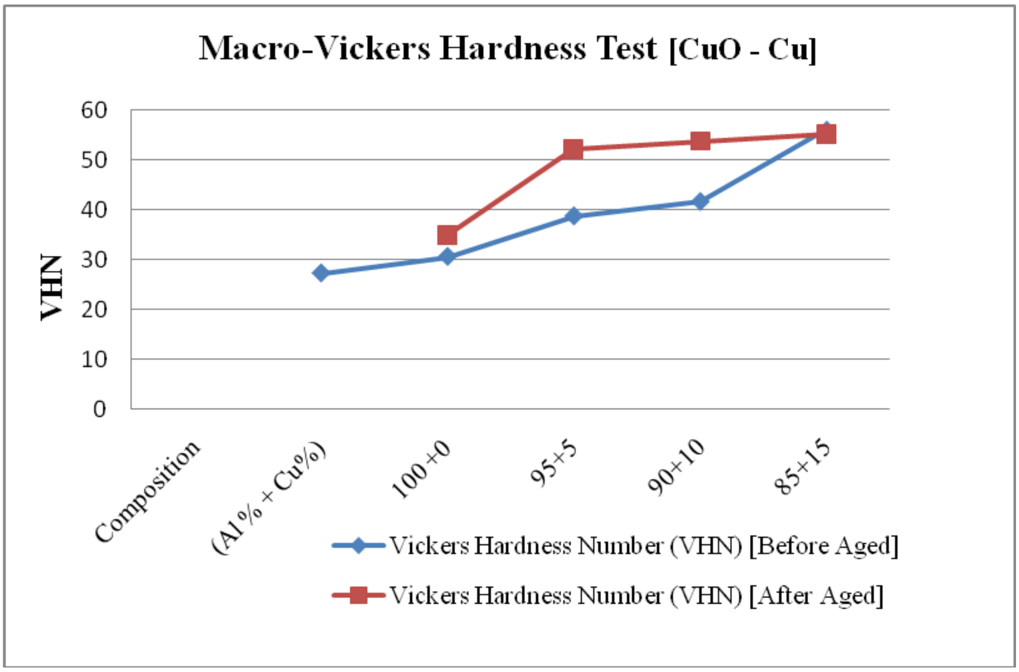


Fig.5.4.1.3: Macro-Vickers hardness before and after aged samples graph, Method-II

Upon completion of the aging process, the hardness values of all samples were once again measured using a macro-Vickers hardness tester machine. It was noted that as the percentages of the reinforcement were increased, there was a corresponding increase in all measured values.

5.5. **Porosity & density measurement**

Upon completion of the measurement process, the subsequent values have been listed in the table 5.4.4. Through these experiments, it was seen that the reinforcement percentages, specifically the copper content, were systematically increased, and there was a corresponding slight rise observed in porosity values. A discernible enhancement in sintered density was observed with the addition of copper. Conversely, the percentage porosity exhibited a notable surge, particularly with the rapid augmentation of copper reinforcement.

Table 5.5.1: Density & Porosity

Method-I

Sl. No.	Composition (Al % + Cu%)	Density as per ROM Theory (gm/cc)	Compact Density (gm/cc)	Compact Porosity (%)	Sintered Density (gm/cc)	Sintered Porosity (%)
1	Pure Aluminium	2.7	2.2	2.72	2.36	2.52
2	Al-5Cu	3.013	2.43	4.23	2.82	3.57
3	Al-10Cu	3.326	2.48	4.47	2.88	4.42
4	Al-15Cu	3.639	2.49	3.96	2.86	3.67
5	Al-20Cu	3.952	2.50	3.74	2.85	2.33

Table 5.5.2: Density & Porosity

Method-II

Sl. No.	Composition (Al % + Cu%)	Compact Density (gm/cc)	Compact Porosity (%)	Sintered Density (gm/cc)	Sintered Porosity (%)
1	Pure Aluminium	2.2	2.72	2.36	2.52
2	Al-5Cu	2.39	8.60	2.71	4.03
3	Al-10Cu	2.45	8.68	2.73	2.54
4	Al-15Cu	2.45	10.68	2.84	4.13
5	Al-20Cu	2.43	13.9	2.85	4.87

Likewise, the tables also provide insights into the compacted and sintered density, as well as the porosity of all composite samples, subsequent to the measurement of these calculated values. It became evident that as the percentages of copper content increased, there was a corresponding rise observed in the values.

CHAPTER– 6

Conclusion & Future Scope

6.1.Conclusion

In this present study, a comprehensive investigation was conducted into the apparent density, porosity, microstructure, and hardness of Al-Cu samples, varying the percentages of copper (Cu) within the Al matrix. The principal findings are elucidated as follows:

- The fabrication of the Al-Cu composite was executed with precision across a spectrum of weight percentages, encompassing 5 wt%, 10 wt%, 15 wt%, and 20 wt% of Cu content within the Al matrix. This was achieved adeptly at a temperature of 600°C using the powder metallurgy (P/M) route.
- A meticulously planned investigation was undertaken to ascertain the reduction of copper oxide (CuO) to dextrose within an inert atmosphere. This meticulous process involved the gradual introduction of nitrogen gas at an elevated temperature of approximately 650°C. Subsequently, the X-ray diffraction (XRD) results were meticulously scrutinized to assess the state of the copper powder.
- A discernible enhancement in sintered density was observed with an incremental rise in sample composition. Conversely, the percentage porosity exhibited a notable surge, particularly with the rapid augmentation of copper reinforcement.
- An insightful comparison between the conventional technique and the reduction process highlighted discernible alterations in structural morphology, effectively demonstrated through optical microscopy.
- The introduction of copper content was found to significantly augment the susceptibility of Vickers hardness. Remarkably, the highest hardness value was recorded in the Al-20 wt% Cu sample. Additionally, in aged Al-Cu samples, there was a rapid escalation in macro-Vickers hardness values.
- Recognized for its lightweight properties, aluminum experiences a substantial enhancement in mechanical properties with the incorporation of copper. This enhancement translates into manifold advantages across diverse industries, notably in aerospace and automobile applications. These benefits extend to components such as leaf springs in suspension systems and pistons in select diesel engines, among myriad others.

6.2. Future Scope

As various stages of the project development unfolded, numerous significant observations were noted, warranting further investigation and research. The following aspects merit inclusion in future studies aimed at advancing the development of new composite materials:

a) There is a pressing need for improved control over the grain size, particle dimensions, and morphology of Al-Cu composites to augment their mechanical properties.

b) The current investigation solely employs the P/M technique. Exploring alternative methodologies and conducting comparative analyses would facilitate more robust conclusions.

c) Conducting a comprehensive cost analysis of these composites is essential to evaluating their economic viability for industrial applications, such as the automotive and aerospace sectors. This includes assessing materials used for antenna supports, ship construction (e.g., propellers), connecting rods, and brake components.

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