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"Effect Of Reinforcement In Hybrid Aluminium Composite And Their Characteristics"

Submitted by

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ABSTRACT

Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements. Now a days the particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components.

Aluminium alloys are widely used in aerospace and automobile industries due to their low density, better wear and corrosion resistance, low thermal coefficient of expansion and other good mechanical properties as compared to conventional metal and alloys. The excellent mechanical properties and relatively low production cost make them a very attractive for a variety of applications both from scientific and technological viewpoints.

The present investigation has been focused on the literature survey of the metal matrix composites produced by different methods. The aim is involved at developing metal matrix composite to combine the desirable attributes of metals and ceramics.

CHAPTER-1 INTRODUCTION

Composite materials consist of two or more microstructurally distinct components that retain their separate identities within the final product. The constituents are fused at the macroscale and are mutually insoluble. The continuous phase, termed the matrix, delineates the outer boundary and provides spatial integrity, while the interior reinforcement phase improves targeted properties—commonly mechanical ones such as tensile strength, flexural rigidity, or thermal stability.

Typical composite architectures exhibit a two-phase morphology, where the continuous matrix envelops discrete reinforcement particles, fibers, or layers. Composite functionality arises from a synergy of the individual constituents and from the microstructural design, which includes volume fraction, spatial distribution, and geometric configuration of the reinforcement.

Through careful material selection and hierarchical design, engineers can tailor composite microstructures to achieve superior performance to monolithic materials such as metals, ceramics, or unfilled polymers. Key performance metrics such as specific modulus, specific strength, and environmental resistance are often enhanced, rendering composites indispensable in demanding sectors such as aerospace, automotive, and infrastructure.

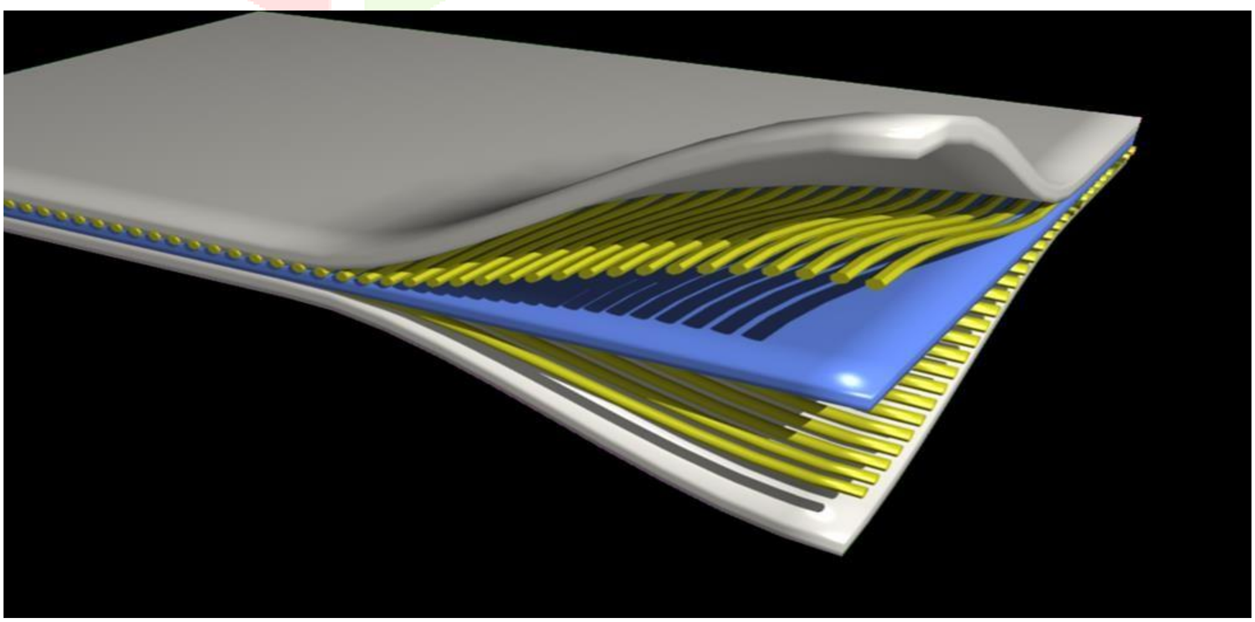


Fig. 1.1 Pictorial view of Composite

1.1 CONSTITUENTS OF COMPOSITE MATERIAL

There are mainly two Constituents of Material:

- Matrix
- Reinforcement

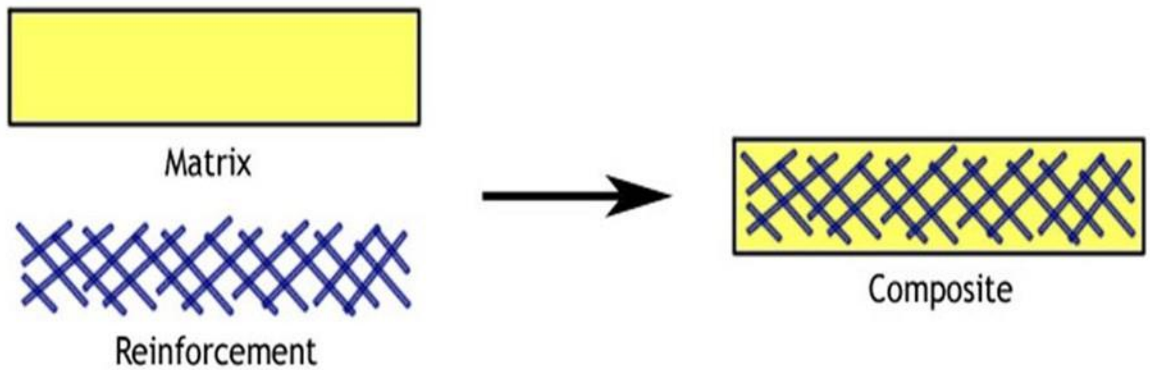


Fig. 1.2 Constituents of Composite material

Matrix:

In composite materials, the matrix acts as the fundamental continuous phase, embedding the reinforcement uniformly and permitting uninterrupted paths through the composite. This isotropic spread distinguishes it from layered systems. When used in structural applications, the matrix usually consists of lightweight metallic alloys—aluminium, magnesium, or titanium—selected for their capacity to confer ductility, toughness, and support under service loads. In demanding thermal regimes, cobalt and cobalt-nickel alloys serve as matrices, offering exceptionally high thermal resistance and oxidative stability.

Reinforcement:

Reinforcement constitutes the dispersed phase engineered to augment the composite's mechanical and physical performance. While it may contribute directly to load-bearing capacity, its primary roles frequently lie in enhancing specific attributes such as wear resistance, thermal diffusivity, and tribological behaviour.

Reinforcements are generally classified as continuous or discontinuous:

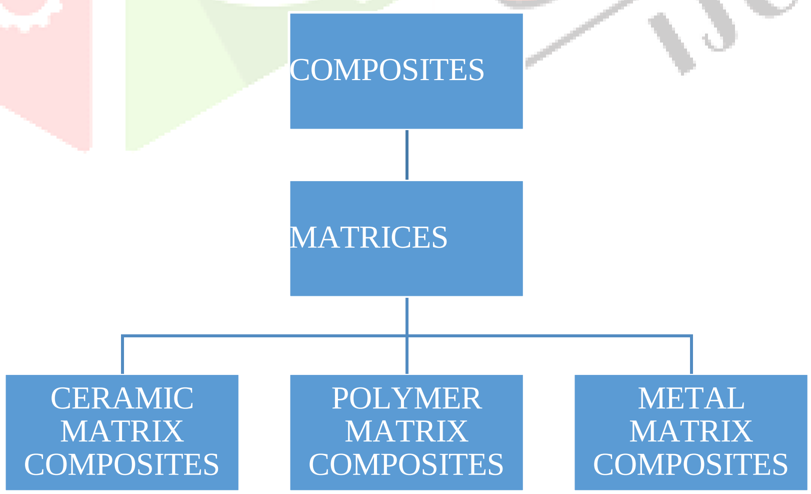
Continuous Reinforcement comprises lengthy fibres or monofilaments: exemplified by carbon fibres or silicon carbide whiskers—precisely oriented along predetermined axes. This orientation imparts anisotropic behaviour to the composite, such that mechanical properties such as tensile strength and elastic modulus are directionally dependent and exceed those of the isotropic matrix by orders of magnitude along the fibre paths.

Discontinuous Reinforcement: is characterized by the inclusion of short fibers, whiskers, or fine particulate phases. Typical matrix components are alumina and silicon carbide. The resulting composites display isotropic mechanical behavior, which permits processing by standard metallic fabrication methods and concurrently ensures that material properties remain consistent across all orientations.

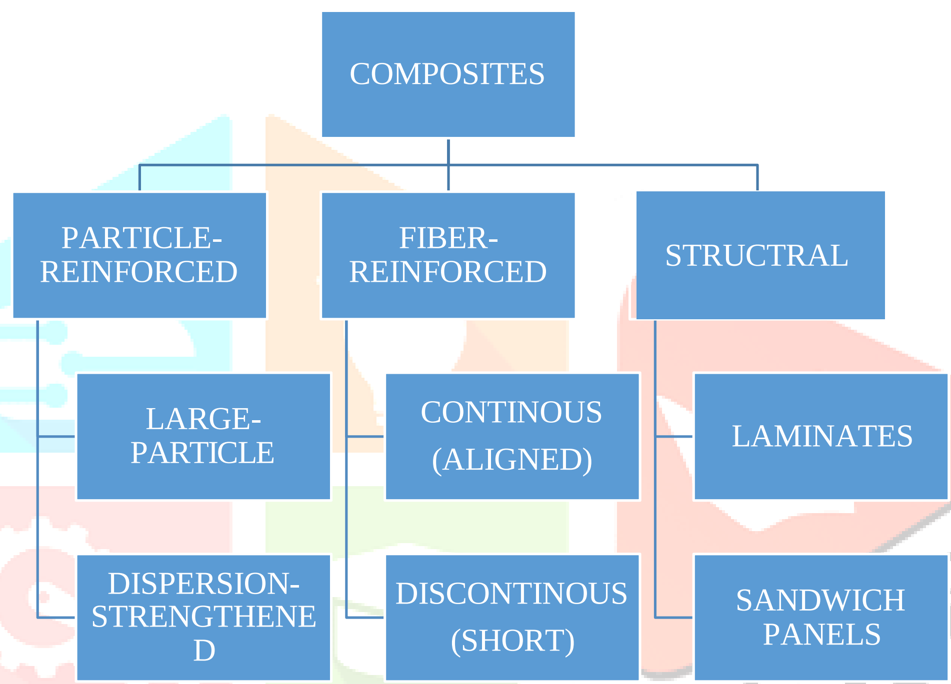
1.2 CLASSIFICATION OF COMPONENT

Composite materials can be systematically delineated at two primary analytical tiers: the structural architecture of the composite and the intrinsic chemical nature of its constituent phases. The foundational tier of classification hinges upon the identity of the continuous matrix, which governs processing pathways, dispersion-phase interaction, and the composite's mechanical and thermal comportment. Accordingly, composites are aggregated into three principal families: metal matrix composites (MMCs), polymer matrix composites (PMCs), and ceramic matrix composites (CMCs). MMCs employ metallic matrices, often selected from aluminium, magnesium, or titanium alloys, and achieve elevated specific strength coupled with commendable thermal stability, particularly at elevated service temperatures. PMCs, which incorporate either thermoplastic or thermosetting resins, are prevalently adopted in the automotive and aerospace sectors, attributable to low density and versatile fabrication techniques. CMCs, consisting of continuous ceramic matrices, exhibit superior thermal stability and oxidation resistance, positioning them favourably for applications subjected to severe thermal and oxidative environments.

The second tier of composite classification is predicated upon the morphology and arrangement of the reinforcing phase embedded in the continuous matrix. These reinforcements are specifically selected to modulate mechanical and thermal characteristics of the composite material; typical design targets include elevated strength, increased stiffness, and improved thermal stability. Reinforcements are, according to morphology, allocated into three primary types: particles, fibres, and laminates. Particle-reinforced composites are formulated with fine, discrete inclusions and primarily serve to augment hardness and resistance to abrasive wear. They are further subdivided into composites dominated by large particles and those characterized by a uniform dispersion of nanoscale reinforcements. Fibre-reinforced composites, conversely, employ either continuous (aligned) fibres or discontinuous (short or randomly oriented) fibres and are adept at enhancing tensile and flexural strength. Lastly, structural composites, exemplified by laminate stacks and sandwich constructions, consist of superimposed strata of varying material compositions that are bonded together; this architecture permits the designer to engineer spatially varying mechanical responses tailored to the demanding requirements of aerospace and civil engineering applications.



The secondary classification schema for composite materials hinges on the geometry and arrangement of the reinforcement phase embedded within the continuous matrix. Reinforcement types decisively govern the mechanical performance enhancement afforded by the composite, and their spatial disposition dictates parameters such as ultimate strength, elastic modulus, and service-life durability. Reinforcements are conventionally classified into particulate, fibrous, and structural categories. Particulate reinforcements are sub-millimetric dispersions of inert or reinforcing particles embedded homogeneously, principally aimed at augmenting wear resistance, hardness, and dimensional stability; their scale may range from a few micrometers to several hundred micrometers according to the designer's intent. Fibrous reinforcements, on the other hand, comprise continuous or discontinuous filaments: continuous filaments, usually aligned parallel to the load axis, impart enhanced mechanical properties in the loading direction, while discontinuous filaments, whether randomly oriented or of short length, yield relatively uniform performance in three dimensions and simplify processing. Structural composites such as laminate stacks or sandwich constructions attain tailored mechanical behaviour by arranging sequential material layers or combining heterogeneous core and skin materials; such configurations are optimised for specific sectors, including aerospace, marine, and automotive engineering. This hierarchical classification therefore affords the designer a rational framework for matching reinforcement geometry and layout to the mechanical and service-life requirements of the application.



1.3 ADVANTAGES & DISADVANTAGES OF COMPOSITE MATERIALS

ADVANTAGES

- Improved tribological properties i.e. friction, lubrication and wear.
- High resistance to impact damage.
- High strength.
- High resistance to corrosion degradation.
- Light in weight.
- Dimensionllly stable they have very low therma expansion. DISADVANTAGES

- High cost raw material & Fabrication.
- Recycling and environmentally safe disposal of composite materials present significant challenges.
- Standard design data is limited.
- High volume production are not available or limited.
- More brittle than wrought metals.

1.4 Metal Matrix Composites (MMCs)

Metal Matrix Composites (MMCs) are engineered materials made by combining a metallic base—such as aluminium, magnesium, copper, or iron—with a secondary phase that may be either ceramic (like oxides or carbides) or metallic (such as lead, tungsten, or molybdenum). Ceramic reinforcements commonly include materials like silicon carbide, alumina, boron carbide, silicon nitride, and boron nitride. On the other hand, metallic reinforcements can involve elements like tungsten or beryllium, depending on the application requirements.

MMCs have found applications in several advanced and high-performance sectors, including aerospace (e.g., components in space shuttles and commercial aircraft), automotive, electronic packaging, sports equipment (like bicycles and golf clubs), and military-grade systems. One of the primary advantages MMCs offer over polymer-based composites is their ability to retain strength, stiffness, and dimensional stability even at elevated temperatures. Additionally, MMCs often show superior resistance to wear, creep deformation, and thermal stress.

Despite these benefits, MMCs are still undergoing extensive development, and their widespread adoption is somewhat limited due to the complexity and high cost of their fabrication processes. Unlike polymer composites, MMCs are not yet as widely implemented in large-scale production environments. However, they also offer several unique physical advantages, including negligible moisture absorption, inherent flame resistance, low thermal and electrical conductivity in some cases, and excellent radiation shielding capabilities.

The key goals in the advancement of metal matrix composites include:

- Enhancing yield and tensile strength at both ambient and elevated temperatures while maintaining essential ductility and toughness.
- Improving resistance to creep deformation under high-temperature conditions.
- Boosting fatigue strength, particularly for cyclic loading in high-temperature environments.
- Increasing resistance to thermal shock and corrosion.
- Achieving higher stiffness by improving Young's modulus.
- Minimizing thermal expansion to ensure better dimensional stability under fluctuating temperatures.

1.5 Metallic Matrix Types

A diverse selection of metallic matrices can be employed in the manufacturing of metal matrix composites, each yielding unique benefits tailored to the target operational environment. Aluminium alloys are among the most prevalent choices, predominantly in aerospace and transportation sectors, owing to their low specific mass, favorable specific strength, and excellent resistance to corrosion. Incorporation of ceramic reinforcements within an aluminium matrix results in a composite that achieves higher tensile and compressive strength while maintaining acceptable ductility, thus suiting it for load-bearing structural applications.

Studies of titanium alloys identify them as a critical matrix for demanding aerospace environments, owing to their elevated yield strength and superior oxidation resistance at elevated temperatures. The premium cost of titanium, however, curtails adoption in applications where economic factors outweigh performance requirements. For applications where mass minimization is paramount, magnesium alloys—having a nominal density of approximately 1.74 g/cm³—have become the matrix of choice; these alloys are routinely employed in lightweight enclosures for aerospace gearbox assemblies, handheld power tools, and portable electronic devices.

Copper alloys are widely employed as matrix materials, particularly in thermal and electrical systems, owing to the high electrical conductivity of elemental copper and its favorable fabrication characteristics. One prominent application is in the manufacture of superconducting composites, where copper serves as the matrix phase and niobium-based reinforcements are embedded to form a robust, current-carrying architecture. Intermetallic compounds, while characterized by brittleness and limited ductility, are occasionally selected as matrix phases in specialized composites. When such phases are combined with tailored reinforcements and optimized processing routes, it is possible to achieve a balanced combination of toughness and high-temperature stability, thereby extending the operational envelope of the composite in demanding environments.

1.6 Manufacturing Processes of Metal Matrix Composites (MMCs)

Metal Matrix Composites are produced through several fabrication pathways, which are selected according to the matrix and reinforcement types, the target mechanical and thermal characteristics, and the specific service environment. The principal processing strategies are generally assigned to solid, liquid, semi-solid, and vapor categories.

Solid-state routes predominantly employ powder metallurgy, whereby metal powders are milled with reinforcement particulates, pressed into compact form, and sintered to achieve full density. Alternatively, foil diffusion bonding can be applied, whereby alternating metal foils and reinforcement layers are stacked, heated, and subjected to pressure, yielding atomic-scale bonding throughout the laminate.

Liquid-state techniques attract attention for their cost-effectiveness and compatibility with high-volume output. The most widespread method is stir casting, in which solid reinforcement is introduced to molten metal and agitated prior to pouring. Complementary techniques encompass electroplating and electroforming, in which the metal matrix is crystallographically deposited onto the reinforcement scaffold; squeeze casting, where liquid metal is forced into a preformed structure; spray deposition, characterized by droplet atomization and quenching; and reactive processing, which entraps reinforcing phases through exothermic reactions between precursor constituents.

Semi-solid processing integrates the behaviors of solid and liquid states to optimize material properties. Among its strategies, semi-solid powder processing involves controlled partial melting of the powder mixture followed by compaction, yielding improved compositional homogeneity and diminished porosity.

Complementing these methods, vapor-deposition techniques, most notably physical vapor deposition (PVD), enable the atomic-scale deposition of matrix materials onto reinforcement particles. This approach is widely adopted in applications demanding elevated performance or component dimensions at the micro-scale.

Chapter : 2

Review of Literature

2.1 Literature Review – Summary Table

No.	Author(s)	Matrix	Reinforcement	Key Findings
1	K.K. Alaneme, M.O. Bodurin	AA 6063	Alumina	Mechanical strength and hardness improved; ductility and fracture toughness reduced with more alumina.
2	V. Ramakoteswara Rao et al.	AA 7075	Titanium Carbide	Wear resistance enhanced as TiC content increased.
3	K.M. Shorowordi et al.	Pure Aluminium	SiC, Al_2O_3, B_4C	B_4C particles showed superior distribution compared to SiC and alumina.
4	Dinesh M. Pargunde et al.	Pure Aluminium	Silicon Carbide	Uniform SiC dispersion; hardness and density increased, impact strength slightly decreased.
5	Vicky Kumar et al.	Pure Aluminium	Silicon Carbide	Noted improvement in hardness and wear resistance.
6	D. Sujan et al.	AA 356	Al_2O_3, SiC	Composite showed better tensile strength and hardness over base alloy.
7	Amir Hussain Idrisi, Shailendra Deva	AA 5083	Silicon Carbide	Hardness and density rose with increased SiC content.
8	Ashok K. Mishra et al.	AA 6061	Silicon Carbide	More SiC increased wear resistance significantly.
9	K. Hemalatha et al.	AA 6063	Aluminium Oxide	Tensile and hardness improved; elongation reduced with more Al_2O_3.
10	S.A. Mohan Krishna et al.	AA 6061	SiC, Graphite	Hybrid composite showed better thermal performance than single-reinforced matrix.
11	Md. Habibur Rahman, H.M. Mamun Al Rashed	Pure Aluminium	Silicon Carbide	Al–SiC composites exhibited superior strength, hardness, and wear resistance compared to unreinforced aluminium.
12	Manoj Kumar Pal et	Zinc	Nickel	Mechanical and thermal

No.	Author(s)	Matrix	Reinforcement	Key Findings
	al.			properties like tensile strength and hardness varied with changing Ni content.
13	Shubhranshu Bansal, J.S. Saini	AA 359	SiC, Graphite	SEM analysis revealed visible cracks and surface defects such as grooves and ploughing marks.
14	M. Mabuchi et al.	AA 5052	Silicon Nitride	The composite displayed excellent superplastic deformation at high strain rates.
15	A. Dolatkhah et al.	AA 5052	Silicon Carbide	Nano-sized SiC particles led to refined grains and enhanced microstructure.
16	N. Kumar et al.	AA 5052	Zirconium Diboride (ZrB_2)	Coefficient of friction increased with higher ZrB_2 content.
17	Feng Tang et al.	AA 5083	Boron Carbide	Higher B_4C content resulted in reduced wear rate of the composite.
18	Ali Alizadeh, Alireza Abdollahi	AA 5083	CNTs, B_4C	CNTs reduced hardness and creep resistance, but hybrid B_4C addition improved mechanical properties.
19	Abhilash A, Dr. Prabhakar Kammar	AA 5083	Fly Ash	Corrosion rate was minimized with increasing exposure time.
20	Tushar Soni et al.	AA 5083	Fly Ash, SiC	Up to 5% reinforcement improved all key mechanical properties; beyond 5%, performance declined.
21	Senthilkumar T.S., Senthil Kumar S.	AA 5083	Silicon Carbide	Metallurgical image analysis showed phase distribution and volume fraction of SiC in the

No.	Author(s)	Matrix	Reinforcement	Key Findings
				composite.
22	Byung-Wook Ahn et al.	AA 5083	Silicon Carbide	Grain refinement was achieved due to pinning effects of SiC in the stir zone.
23	Sourabh Gargatte et al.	AA 5083	Silicon Carbide	Optimization of wear parameters was done using Taguchi method, ANOVA, and regression models.
24	Meijuan Li et al.	AA 5083	Titanium Diboride (TiB_2)	TiB_2-reinforced composites were successfully synthesized using cryomilling and spark plasma sintering.
25	Yong Li, Terence G. Langdon	AA 6061	Alumina	Incorporating 20 vol.% Al_2O_3 significantly improved the creep resistance of the composite.
26	Hamid Reza Ezatpour et al.	AA 6061	Alumina	Nanocomposites displayed fine-grain structure but showed increased porosity.
27	P. Maheswaran, C.J. Thomas Renald	AA 6061	Graphite, Al_2O_3	Wear performance was enhanced by combined addition of graphite and alumina.
28	A.G. Wang, I.M. Hutchings	AA 6061	Alumina Fiber	Abrasive particle size influenced the transition in wear behavior of the composite.
29	T.G. Nieh, R.F. Karlak	AA 6061	Boron Carbide	B_4C addition accelerated age hardening, particularly at low temperatures.
30	K. Kalaiselvan et al.	AA 6061	Boron Carbide	Optical and XRD analysis confirmed uniform distribution of B_4C particles in the matrix.

No.	Author(s)	Matrix	Reinforcement	Key Findings
31	T. Nakamura, S. Suresh	AA 6061	Boron Fiber	Partial yielding in the matrix during transverse loading led to reduced apparent stiffness of the composite.
32	B.G. Park, A.G. Crosky, A.K. Hellier	AA 6061	Mullite, Alumina	Composites demonstrated higher elastic modulus, yield, and tensile strength than the base alloy.
33	R.M. Wang et al.	AA 6061	Silicon Carbide	SiC particles exhibited strong bonding with the aluminium matrix.
34	S. Nallusamy, A. Karthikeyan	AA 6061	Al_2O_3, SiC	SEM analysis revealed both micro and transverse cracks, with varying degrees of surface wear.
35	Denise M. Aylor, Patrick J. Moran	AA 6061	SiC, Graphite	SiC addition did not impact corrosion potential or pitting behavior in ocean water.
36	D.F. Hasson et al.	AA 6061	SiC Whiskers	Considerable improvements were noted in modulus, yield stress, and ultimate tensile strength.
37	A. Chennakesava Reddy, Essa Zitoun	AA 6061	Silicon Carbide	Fractography showed that SiC particles remained intact, indicating strong interfacial bonding.
38	Madeva Nagaral et al.	AA 6061	Alumina, Graphite	Wear resistance improved with the hybrid addition of Al_2O_3 and graphite.
39	K. Umanath et al.	AA 6061	SiC, Al_2O_3	Microstructural studies confirmed uniform distribution of both reinforcements in the

No.	Author(s)	Matrix	Reinforcement	Key Findings
				aluminium matrix.
40	J.B. Fogagnolo et al.	AA 6061	Aluminium Nitride	Composite powders prepared via mechanical alloying and extruded showed enhanced properties.
41	T.V. Christy, N. Murugan, S. Kumar	AA 6061	Titanium Diboride (TiB_2)	Composite showed increased hardness, tensile strength, and Young's modulus compared to unreinforced alloy.
42	S. Gopalakrishnan, N. Murugan	AA 6061	Titanium Carbide (TiC)	A slight increase in wear rate was observed with higher TiC content.
43	Pardeep Sharma, Dinesh Khanduja, Satpal Sharma	AA 6082	Graphite	Wear resistance of the composite was significantly improved over base AA6082 alloy.
44	Pardeep Sharma et al.	AA 6082	Si_3N_4, Graphite	Wear reduced with increased reinforcement and sliding speed, but increased under higher load and sliding distance.
45	Shashi Prakash Dwivedi et al.	AA 6082	Silicon Carbide	Low porosity levels observed in the composite containing 25µm SiC particles.
46	P.R.K. Fu et al.	AA 6082	Al_2O_3, SiC	Al–Al_2O_3 composites had lower wear rates; Al–SiC composites showed increased wear at higher SiC percentages.
47	N. Ch. Kaushik, R.N. Rao	AA 6082	SiC, Graphite	Higher load increased wear rate; sliding distance had minimal impact on performance improvement.
48	Arumugam Thangarasu et al.	AA 6082	Titanium Carbide (TiC)	Optical and SEM analysis confirmed uniform TiC dispersion; microhardness of composite improved.
49	Pardeep Sharma et al.	AA 6082	Si_3N_4, B_4N	Metallographic images confirmed well-distributed reinforcement particles using ball milling.
50	Shailesh Singh, Shashi P. Dwivedi, Harveer S. Pali	AA 6082	Silicon Carbide	Tensile strength improved with higher SiC content.
51	M.A. Taha et al.	AA 6082	Silicon Carbide	Stir casting voids reduced; SiC clusters rearranged along the

No.	Author(s)	Matrix	Reinforcement	Key Findings
				rolling direction after processing.
52	Ambachai Thanyasai et al.	AA 6061	Egg Shells	Stir-cast composites showed increased hardness but reduced density with egg shell reinforcement.
53	T.B. Asafa et al.	Aluminium	Snail Shell	Stir casting resulted in improved strength and hardness due to snail shell reinforcement.
54	Sefiu A. Bello et al.	Aluminium (XXX1)	Coconut Shell	Addition of coconut shell increased hardness and tensile strength in stir-cast composites.
55	Sunday A. Fakorede et al.	AA 6063	Snail Shell Ash	Composite exhibited higher hardness and improved corrosion resistance after stir casting.

CHAPTER – 3 RESEARCH GAP

A systematic appraisal of the current literature reveals that considerable advancements have been directed toward refining the properties of aluminium metal matrix composites (AMMCs) produced by heterogeneous processing routes. The synthesis of previous findings permits their clustering into several principal domains of contribution:

1. Relatively few investigations have systematically assessed the impact of processing variables on critical mechanical metrics—including tensile strength, hardness, and relative density—of aluminium matrix composites, thereby highlighting a persistent deficiency in a unified and detailed mechanistic framework.

2. Equally, studies that interrogate the mechanical behaviour of AA6063-based composites reinforced with silicon carbide (SiC) and bio-derived corn cob in a coherent and extensive combination of reinforcement phases are scarce, bordering on absent, particularly with regard to the exploration of ternary or higher-order reinforcer assemblages.

3.1 SELECTION OF MATRIX MATERIAL

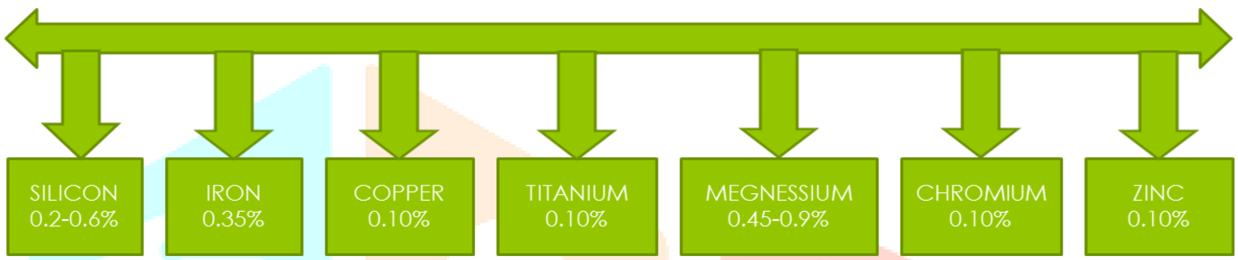
Selection of Matrix Material – AA 6063

AA 6063 ranks among the most frequently specified aluminium alloys, with alloying elements of magnesium and silicon defining its microstructure. The alloy's limit specifications for chemical composition and mechanical characteristics are established by The Aluminum Association. The material exhibits an advantageous balance of yield and ultimate tensile strength, good resistance to atmospheric and aqueous corrosion, excellent weldability, and responsiveness to both artificial and natural aging processes. For many applications, these attributes render it a pragmatic choice, and it may be considered equivalent in composition and functionality to the British alloy HE9.
Particularly notable is AA 6063's outstanding capacity for extrusion. It can be formed into geometrically complex profiles that sport uniform surface textures, which are highly amenable to protective anodic films.

Such characteristics explain its pervasive use in architectural sectors—window and door frames, roofing elements, curtain walling, and structural glazing systems. In contrast, applications that impose more stringent strength requirements should take into consideration AA 6061 or AA 6082, which, while sacrificing some of the formability of 6063, deliver superior mechanical performance.

In the current study, alloy AA 6063 was chosen as the matrix material on account of its advantageous wettability characteristics with reinforcing particulates, favorable amenability to processing, and its significance in structural and load-bearing applications. The alloy possesses a balanced combination of mechanical and physical attributes that render it an appropriate substrate for the fabrication of advanced metal matrix composites.

Chemical Composition of the AA6063.



3.2 SELECTION OF REINFORCEMENT MATERIAL

A. Silicon Carbide-Aluminium MMC

Aluminium matrix composites (AMCs) reinforced with silicon carbide (SiC) have emerged as a promising class of advanced materials, particularly in high-performance sectors like aerospace and automotive. One of the standout attributes of Al–SiC composites is their exceptional strength-to-weight ratio, which is approximately three times higher than that of conventional mild steel. This makes them highly desirable for applications where reducing weight without compromising strength is critical.

The incorporation of silicon carbide particles into the aluminium matrix significantly enhances mechanical and thermal properties. These composites exhibit superior hardness, increased tensile strength, high elastic modulus, excellent wear resistance, and enhanced thermal stability. Their low density further contributes to improved load-bearing efficiency, making them ideal for structural and dynamic applications.

In addition to mechanical advantages, Al–SiC composites also offer good resistance to corrosion and oxidation. This is largely due to the formation of a stable silicon oxide layer on the surface of SiC at elevated temperatures (around 1200°C), which complements aluminium's natural oxide barrier. Together, these protective layers help the material withstand harsh environmental and thermal conditions.

Given these characteristics, Al–SiC composites are highly suitable for aerospace applications, where materials must endure high mechanical stress and elevated temperatures while maintaining low weight. Their combination of strength, thermal performance, and durability positions them as a valuable material for components such as aircraft frames, engine parts, and structural reinforcements.

Silicon carbide has been selected as a reinforcement material.

B. Corn Cob(C.C)

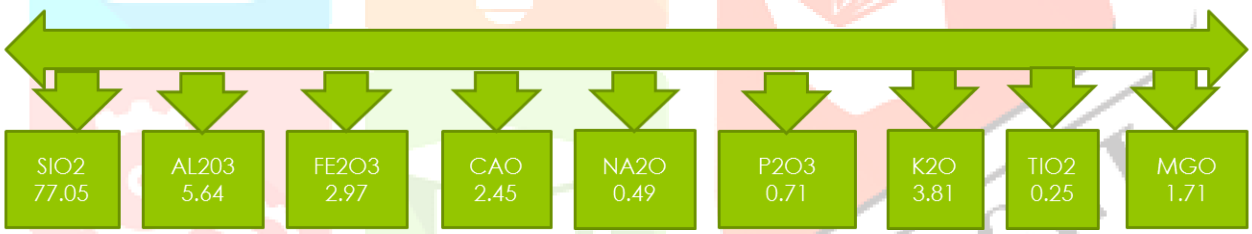
Despite the potential benefits of agro-waste materials—such as low density, economic viability, and satisfactory mechanical performance—research activity on their incorporation into composite systems remains sparse among scholars in developing countries. Recent investigations, however, have pivoted toward the fabrication of aluminium-based hybrid composites that capitalize on corn cob ash (CCA) and silicon carbide (SiC) as dual reinforcement phases.

CCA has emerged as a feedstock of interest primarily owing to its bulk density of approximately 1.96 g/cm³, a value that contrasts markedly with the densities of conventional reinforcements: SiC at 3.18 g/cm³ and aluminium oxide (Al_2O_3) at 3.9 g/cm³. The feedstock is abundantly available in peri-urban and rural agroeconomic zones, particularly within developing economies, and its processing demands are minimal. Such characteristics render CCA a viable, environmentally benign reinforcing agent that not only attenuates the composite's overall mass but also promotes sustainable material lifecycles through the valorisation of agricultural residues.

The strategic integration of CCA and SiC within an aluminium matrix, therefore, delineates a pathway toward the manufacture of competitively priced and lightweight composites that retain adequate mechanical and thermal properties. These materials are well positioned for deployment in a spectrum of engineering applications where performance and economic considerations are paramount.

Corn Cob has been selected as a reinforcement material.

CORN COB COMPOSITION



3.3 Selection of Fabrication Method

A variety of techniques are employed to fabricate aluminium matrix composites (AMCs), including powder metallurgy, ball milling, friction stir processing, and pressure-less infiltration. Among these, conventional stir casting is frequently regarded as the most cost-effective and commercially viable approach. Its capability to form intricate geometries, coupled with the flexibility to incorporate diverse reinforcements and a broad spectrum of processing parameters, renders it especially attractive for industrial implementation.

The **stir casting** process promotes enhanced interface bonding between the aluminium matrix and the reinforcing particles through vigorous mechanical agitation. This promotes a uniform spatial distribution of the reinforcements within the molten alloy, yielding improved mechanical properties and greater structural integrity in the finished composite.The technique's operational simplicity, economic efficiency, and capacity for large-scale production have led to its widespread adoption in various industrial sectors. In light of these advantages, the present study has selected stir casting as the fabrication method for developing aluminium-based hybrid composites.

FIGURE STIR CASTING

CHAPTER :4

OBJECTIVE

Aim and Objectives of the Study

The principal aim of this investigation is to design a financially viable aluminium-based metal matrix composite (MMC) and to rigorously appraise its mechanical properties for viable engineering deployment. The detailed objectives of the enquiry are delineated as follows:

1. To execute an extensive synthesis of the contemporary literature addressing metal matrix composites, concentrating specifically on aluminium matrices and the corresponding reinforcement paradigms.

2. To manufacture an aluminium matrix composite employing the AA6063 alloy as the matrix, supplemented with silicon carbide (SiC) and corn cob powder, and to execute the stir casting process as a low-cost and scalable route.

3. To perform a systematic mechanical characterisation of the produced composite by measuring tensile strength, hardness, and density.

4. To benchmark the mechanical responses of the composite against those of the unreinforced AA6063 alloy, thereby quantifying the efficacy of the reinforcement.

CHAPTER: 5

RESEARCH METHODOLOGY

The methodology enacted within the present investigation comprises a clearly delineated sequence of steps directed toward the synthesis of aluminium matrix composites (AMCs) wherein the alloy AA6063 constitutes the continuous phase and the particulate reinforcements are provided by Corn Cob Ash (CCA) and Silicon Carbide (SiC). The individual procedural components are enumerated hereinafter:

Material Procurement

A sufficient mass of AA6063 alloy was acquired as the matrix phase of the composites. Corn cobs and silicon carbide were also sourced to serve as particulate reinforcements during composite consolidation.

Spectrometric Analysis

A spectrometric assay was performed on the AA6063 alloy and the pre-formed corncobs to ascertain the elemental constitution of each component with precision prior to their subsequent processing.

Preparation of Corn Cob Ash (CCA)

Background Corn Cob Ash was produced by a series of controlled operations:

- The harvested corncobs were dehydrated under solar radiation for a period of three to four days to reduce the moisture fraction.
- The dehydrated corncobs were combusted within a perforated metallic drum to effectuate thermal oxidation.
- The resultant ash was permitted to equilibrate with ambient conditions inside the drum to achieve thermal homogeneity.
- The cooled ash was subjected to a heat treatment cycle in a laboratory muffle furnace, where it was maintained at a temperature of approximately 650 °C for 180 minutes to expel entrained carbonaceous and volatile impurities.
- The processed ash was subsequently subjected to granulation and particle size quantification by means of a sieve shaker, ensuring a narrow size distribution for homogenous incorporation into the metallic matrix.

Powder Processing

Corn cob ash that had been cooled and conditioned underwent ball milling to obtain a fine powder with the requisite particle size for effective reinforcement in the composite material.

Preheating of Reinforcements

Corn cob ash (CCA) and silicon carbide (SiC) particles were preheated to approximately 250 °C. This treatment evaporated residual moisture and optimised particle wettability with the molten aluminium during subsequent mixing.

Melting of AA6063 Alloy

The AA6063 aluminium alloy was introduced into a crucible furnace and heated to a temperature exceeding the liquidus limit, thereby achieving a fully molten state.

Transition to Semi-Solid State

The molten alloy was left to cool in the furnace until a semi-solid temperature of about 600 °C was reached, a condition preferable for incorporating the reinforcement particles.

Introduction of Reinforcements and Manual Stirring

The preheated CCA and SiC particles were then incrementally added to the semi-solid alloy. Manual stirring was continued for 10 minutes, producing a slurry in which the reinforcements were evenly distributed.

Superheating and Mechanical Stirring

The composite slurry was superheated to approximately 800 °C. A mechanical stirrer was then used to stir the mixture continuously, facilitating better interfacial bonding and homogeneity of the reinforcements.

Variation in Composition

The stir-casting operation was systematically repeated with varied mass fractions of the aluminium matrix and the reinforcements, yielding a series of composite samples with different compositions for evaluation.

Mechanical Testing

The produced composite specimens underwent an array of mechanical assessments, specifically tensile strength, hardness measurement, and density determination. The compiled data were cross-referenced among varying formulations to quantify and elucidate how reinforcement volume fraction modulates the macroscopic mechanical response of the composite material.

CHAPTER 6:
RESULTS AND DISCUSSION

6.1 Density Test

To evaluate the impact of Silicon Carbide (SiC) and Corn Cob Ash (CCA) reinforcements in AA6063 alloy, density testing was conducted. CCA, due to its low density (1.69 g/cm³), facilitates weight reduction in the composite. The AA6063 base alloy has a density of 2.69 g/cm³, while SiC possesses a significantly higher density of 3.18 g/cm³.

A decreasing trend in density was observed up to 4% reinforcement with SiC and CCA, attributed to the predominance of low-density CCA. However, a density increase was noted with 5% SiC addition alone, indicating the influence of higher-density SiC on the matrix. This confirms that density variation is directly related to the proportion and nature of reinforcement materials used.

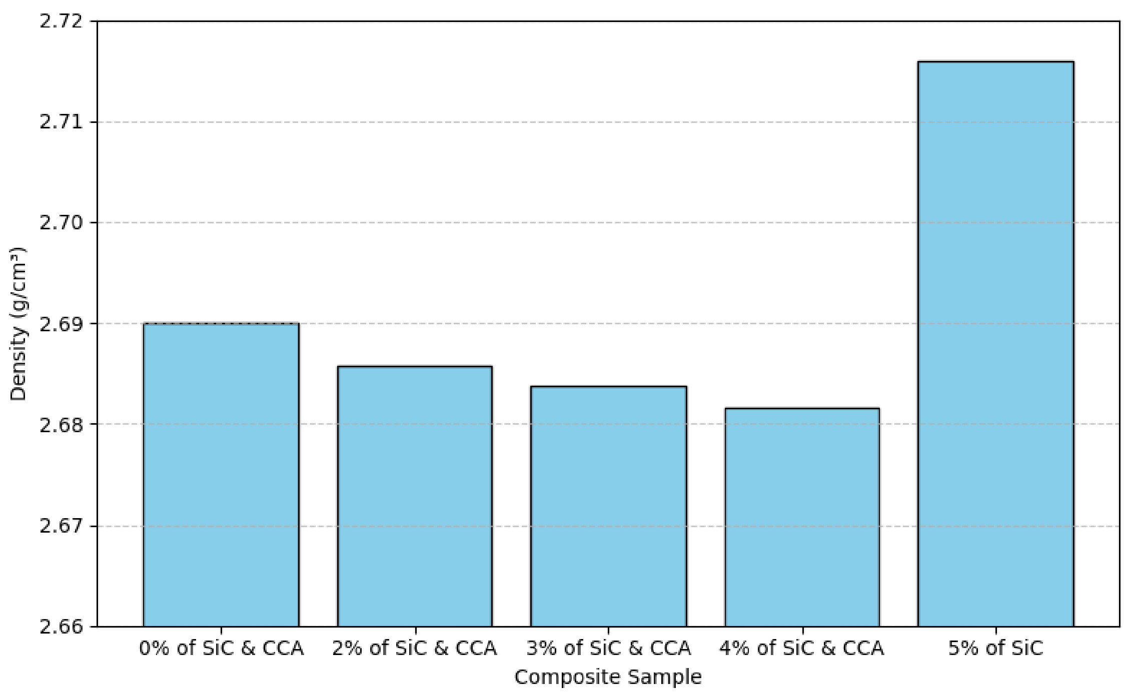


Figure 6.1: Variation in Density with wt.% of SiC and CCA

Figure 6.1 illustrates the variation in density of AA6063-based metal matrix composites reinforced with different weight percentages of Silicon Carbide (SiC) and Corn Cob Ash (CCA). The graph shows a gradual decline in density from 2.690 g/cm³ to 2.6816 g/cm³ as the reinforcement increases from 0% to 4% of combined SiC and CCA. This reduction is primarily attributed to the incorporation of CCA, which has a relatively low density compared to the aluminium matrix and SiC. Interestingly, at 5% reinforcement with SiC alone, the density rises to 2.716 g/cm³, surpassing all previous values. This significant increase can be linked to the higher specific gravity of SiC (3.18 g/cm³), which offsets the lightweight nature of the base alloy. The findings demonstrate that the density of hybrid composites is strongly influenced by the type and proportion of reinforcements used. The inclusion of low-density agro-waste like CCA effectively reduces overall weight, whereas increasing the proportion of dense ceramic reinforcements such as SiC enhances the composite's compactness and mass.

Table 6.1: Composite Density Results

Composite Sample	Reinforcement Type	Density (g/cm³)
Sample 1	0% SiC & CCA (Base AA6063)	2.690
Sample 2	2% SiC & CCA	2.6858
Sample 3	3% SiC & CCA	2.6837
Sample 4	4% SiC & CCA	2.6816
Sample 5	5% SiC only	2.716

6.2 Hardness Test

The Vickers hardness test indicated an increase in hardness values with reinforcement up to 3% of SiC and CCA. This enhancement is attributed to the presence of SiC, which is known to significantly improve hardness due to its high intrinsic strength and resistance to deformation.

However, a decline in hardness beyond 3% was observed. This can be linked to porosity and microstructural flaws, likely arising from incomplete mixing or limitations in the mechanical stirring process. Entrapped air or gas during casting could also lead to reduced hardness, particularly at higher reinforcement concentrations.

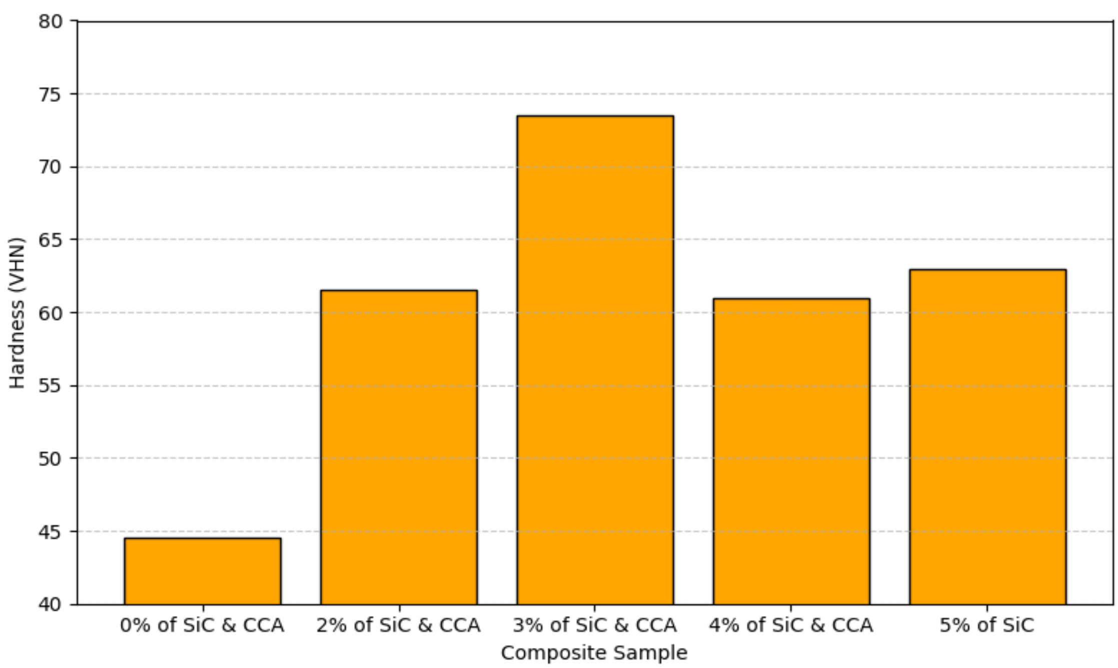


Figure 6.2: Variation in Hardness with wt.% of SiC and CCA

Figure 6.2 depicts the variation in Vickers hardness for AA6063-based composites reinforced with varying weight percentages of Silicon Carbide (SiC) and Corn Cob Ash (CCA). The hardness of the base alloy without any reinforcement was recorded at 44.5 VHN. A progressive increase in hardness was observed with the addition of 2% and 3% SiC–CCA, reaching a peak value of 73.5 VHN at 3% reinforcement. This enhancement is attributed to the presence of hard ceramic particles like SiC, which resist deformation and contribute to higher surface hardness. Beyond 3%, however, a noticeable decline in hardness was observed, with 4% and 5% reinforcement samples registering 61.0 VHN and 63.0 VHN, respectively. This drop is likely due to increased porosity, non-uniform dispersion of reinforcements, and potential agglomeration, which act as stress concentration sites and weaken the matrix. The results confirm that while reinforcement improves hardness initially, excessive addition without proper dispersion control can degrade the mechanical integrity of the composite.

6.3 Yield Stress Test

The addition of reinforcements significantly influenced the yield strength of AA6063. Initial reductions were noted at 2% SiC & CCA, likely due to the limited wettability and bonding of CCA. Yield stress improved from 3% onward, indicating SiC's superior mechanical bonding and load transfer efficiency compared to CCA.

The highest yield strength was recorded at 5% SiC, demonstrating the dominant role of SiC in mechanical performance enhancement. Particle-to-particle contact and agglomeration may have affected stress transfer at lower reinforcement levels.

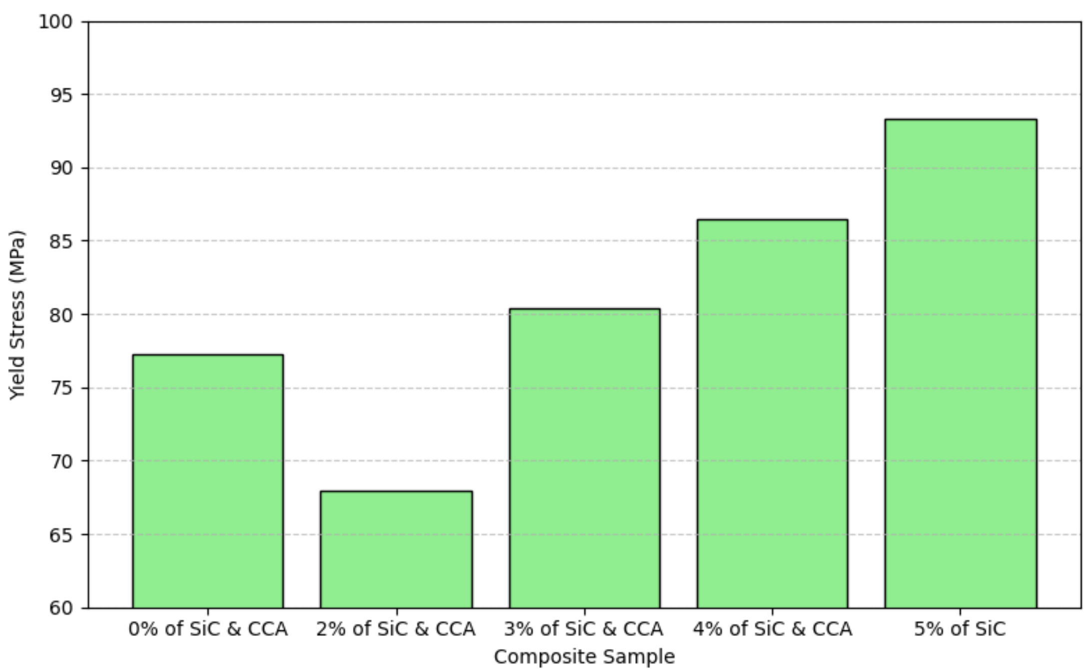


Figure 6.3: Variation in Yield Strength with wt.% of SiC and CCA

Figure 6.3 represents the variation in yield stress of AA6063-based composites as a function of increasing reinforcement content using Silicon Carbide (SiC) and Corn Cob Ash (CCA). The base alloy without any reinforcement recorded a yield stress of 77.25 MPa. An initial decrease was observed at 2% SiC–CCA reinforcement, dropping to 67.95 MPa. This reduction could be attributed to weak interfacial bonding between the soft CCA particles and the aluminium matrix, which compromises load transfer during plastic deformation. However, a clear recovery and improvement in yield stress was seen at higher reinforcement levels—80.35 MPa at 3%, 86.50 MPa at 4%, and peaking at 93.30 MPa with 5% SiC. This upward trend is mainly due to the dominant strengthening effect of SiC, which contributes to better stress transfer, grain refinement, and dislocation blocking. The data highlight the critical role of reinforcement composition and distribution in determining the yield strength of the composite material.

6.4 Ultimate Tensile Strength

The ultimate tensile strength (UTS) followed a steady increase with higher reinforcement content. The UTS improved by 11.22%, 23.39%, and 36.32% for 2%, 3%, and 4% SiC-CCA compositions, respectively. The 5% SiC sample showed a significant 41.52% improvement over unreinforced AA6063.

The uniform dispersion of SiC particles achieved through ball milling and optimized stirring played a vital role in enhancing load-bearing capacity. SiC's higher fineness and hardness contributed to improved tensile response.

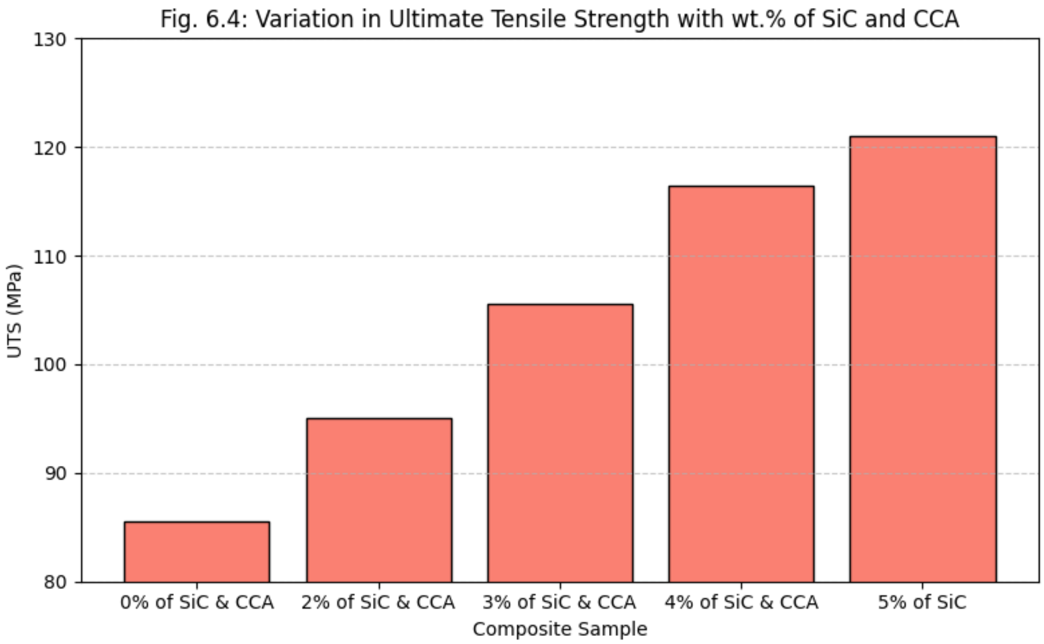


Figure 6.4: Variation in Ultimate Tensile Strength with wt.% of SiC and CCA

Figure 6.4 presents the variation in Ultimate Tensile Strength (UTS) for AA6063 composites reinforced with different proportions of Silicon Carbide (SiC) and Corn Cob Ash (CCA). The UTS of the base alloy without reinforcement was recorded at 85.5 MPa. With the addition of reinforcements, a consistent increase in tensile strength was observed. At 2% reinforcement (SiC + CCA), the UTS rose to 95.1 MPa, showing an improvement of approximately 11.22%. The upward trend continued with 3% and 4% reinforcement combinations, reaching 105.5 MPa and 116.5 MPa respectively. The maximum UTS of 121.0 MPa was achieved with 5% SiC reinforcement alone, indicating an overall enhancement of 41.52% over the unreinforced matrix. This trend reflects the significant influence of SiC's hard ceramic nature and its efficient load-carrying capacity when uniformly distributed in the matrix. Moreover, the hybrid reinforcement with agro-waste CCA contributed to strength improvements up to a certain threshold but may introduce porosity or uneven dispersion if not optimally processed. Overall, the data underscores the reinforcing efficiency of SiC in improving the tensile behavior of aluminium composites.

6.5 Microstructural Analysis

Scanning Electron Microscopy (SEM) was employed to study the microstructure of the composites at different reinforcement levels.

Fig. 6.5a: At 2% SiC & CCA, coarse agglomerates and irregular particle shapes were observed.

Figure 6.5a displays the scanning electron microscopy (SEM) microstructure of the AA6063 aluminium matrix composite reinforced with 2% Silicon Carbide (SiC) and Corn Cob Ash (CCA). The image reveals noticeable **coarse agglomerates** and **irregularly shaped reinforcement particles** distributed unevenly within the matrix. This non-uniform dispersion is likely due to insufficient interfacial bonding and weak wettability of the reinforcements at lower concentrations, especially when using a hybrid of ceramic and bio-based particles. The formation of clusters results in localized regions of high stress and potential weak zones, which can adversely affect the mechanical integrity of the composite. Additionally, the irregular morphology of the CCA particles may have contributed to poor flow characteristics during casting, leading to further inhomogeneity. Overall, this microstructure reflects the typical challenges associated with achieving effective dispersion at minimal reinforcement levels, and it correlates with the comparatively lower mechanical performance observed in hardness and yield strength tests.

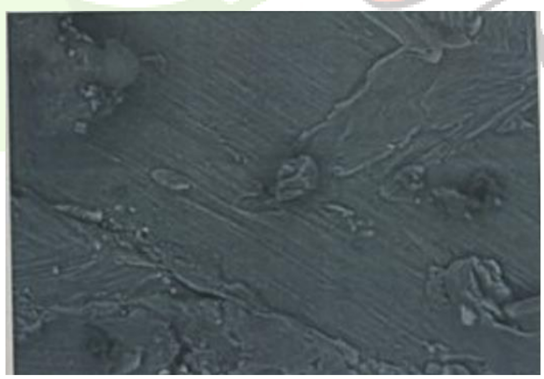


Fig. 6.5b: At 3% SiC & CCA, uniform distribution was achieved with minimal clustering, correlating with improved mechanical performance.

Figure 6.5b illustrates the scanning electron micrograph of the AA6063 composite reinforced with 3% Silicon Carbide (SiC) and Corn Cob Ash (CCA). In contrast to the previous sample, this microstructure shows a **significantly improved dispersion** of reinforcement particles throughout the aluminium matrix. The reinforcement appears more **uniformly distributed**, with minimal evidence of clustering or agglomeration. This suggests that the mechanical stirring and preheating of reinforcements at this composition level were effective in enhancing wettability and interfacial bonding. The SiC particles, owing to their angular and hard nature, are embedded cleanly within the matrix, while the fine bio-ash particles occupy interstitial spaces, potentially aiding load distribution. The relatively homogenous phase structure observed here aligns well with the peak improvements recorded in hardness and tensile strength at this reinforcement level. This microstructure validates that 3% hybrid reinforcement may represent an **optimal balance** between mechanical enhancement and microstructural stability in aluminium matrix composites.

Fig. 6.5c: At 4% SiC & CCA, porosity and casting defects (e.g., shrinkage cavities and gas holes) became visible, which can degrade mechanical properties.

Figure 6.5c presents the scanning electron micrograph of the AA6063 composite reinforced with 4% Silicon Carbide (SiC) and Corn Cob Ash (CCA). The microstructure at this reinforcement level reveals the onset of **casting defects**, including **porosity**, **shrinkage cavities**, and **gas holes**, distributed across the matrix. These defects are indicative of **processing limitations**, possibly due to excessive addition of hybrid reinforcements that hindered proper flow and solidification during the stir casting process. The clustered regions of CCA and partially wetted SiC particles contribute to the formation of voids and discontinuities at the matrix–reinforcement interface. Such imperfections can act as **crack initiation sites** under mechanical loading, potentially leading to reduced ductility and long-term fatigue strength. The irregular distribution also suggests possible sedimentation or inadequate stirring at elevated weight percentages. While some particle embedding remains visible, the increased defect density significantly compromises the structural integrity of the composite. This microstructural deterioration aligns with the observed drop in mechanical performance parameters beyond the 3% reinforcement threshold.

Fig. 6.5d: At 5% SiC, SiC particles were uniformly embedded with minimal defects, affirming effective reinforcement-matrix bonding.

Figure 6.5d displays the scanning electron microscopy (SEM) image of the AA6063 composite reinforced solely with 5% Silicon Carbide (SiC). The microstructure reveals a **uniform and well-distributed**

dispersion of SiC particles within the aluminium matrix, with **minimal defects** such as voids or pores. Unlike earlier compositions, no major clustering or agglomeration is evident, indicating a high degree of compatibility and effective bonding between the matrix and the ceramic reinforcement. The clean particle-matrix interfaces suggest successful mechanical stirring and sufficient wetting during the stir casting process. The angular SiC particles appear firmly embedded, enhancing mechanical interlocking and load transfer efficiency. This improved microstructural integrity contributes directly to the **highest recorded values** in both yield strength and ultimate tensile strength, as observed in the experimental results. Overall, the structure confirms that increasing SiC content—when properly processed—leads to significant improvements in composite uniformity, density, and strength without inducing the casting-related defects seen in hybrid compositions.

CHAPTER 7:

CONCLUSION

This study investigated the fabrication and characterization of AA6063-based metal matrix composites reinforced with Silicon Carbide (SiC) and Corn Cob Ash (CCA) using the stir casting method. The primary objective was to evaluate the influence of varying reinforcement compositions on the composite's mechanical and microstructural properties.

The experimental findings affirm that hybrid reinforcement significantly alters the composite's performance. The inclusion of CCA, a low-density agro-waste material, proved effective in reducing overall material weight while moderately enhancing mechanical characteristics when used in controlled proportions. On the other hand, SiC, a hard ceramic phase, played a dominant role in improving hardness, tensile strength, and yield stress due to its superior stiffness and interfacial bonding with the aluminium matrix.

Mechanical tests revealed that the composite with **3% SiC + CCA** demonstrated optimal balance between hardness and structural integrity, whereas the **5% SiC-only** specimen yielded the highest mechanical strength, especially in terms of **ultimate tensile strength and yield stress**. However, excessive reinforcement, particularly hybrid combinations beyond 3–4%, introduced casting defects such as porosity and clustering, as evidenced in the microstructural analysis.

The SEM results confirmed that uniform particle distribution and minimal casting defects were critical for mechanical enhancement. While lower reinforcement levels showed agglomeration and poor bonding, optimized reinforcement levels led to improved matrix-reinforcement integration and consistent phase morphology.

In conclusion, the study demonstrates that the careful selection of reinforcement type and percentage is essential for achieving a desirable combination of strength, durability, and processability in aluminium matrix composites. The use of agro-waste like CCA, when properly integrated, can promote sustainability without sacrificing performance, while SiC remains a reliable candidate for enhancing the mechanical attributes of structural materials in aerospace, automotive, and industrial applications.

REFERENCES

[1] Autar K. Kaw, Mechanics Of Composite Materials, pg.-2.

[2] S.Bandyopadhay, T.Das , and P.R.Munroe ,Metal Matrix Composites -The Light Yet Stronger Metals For Tomorrow, A Treaise On Cast materials, p-17-38.

[3] T.W.Clyne, (2001), Metal Matrix Composites: Matrices and Processing, Encyclopedia of Materials : Science and Technology, pg- 8.

[4] Composite Materials: Engineering and Design by F.L.Matthews and R.D.rawlings, Chapman & Hall publication.

[5] Chawla, Krishan Kumar, Composite Materials: Science and Engineering, pg. 165 – 168.

[6] K.K. ALANEME, M.O.BODURIN Acta Technica Corviniensis-Bulletin of Enginnering Tome VI (year 2013)-Fascicule3 [July-September] ISSN 2067-3809.

[7] V. Ramakoteswara Rao, N. Ramanaiah and M. M. M. Sarcar, International Journal of Advanced Science and Technology Vol.88 (2016), pp.13-26.

[8] K.M. SHOROWORDI , T. LAOUI, A.S.M.A. HASEEB, J.P. CELIS, L. FROYEN, Journal of Materials Processing Technology 142 (2003) 738–743.

[9] DINESH M. PARGUNDE, GAJANAN N. THOKAL, DHANRAJ P. TAMBUSKAR, SWAPNIL S. KULKARNI "DEVELOPMENT OF ALUMINIUM BASED METAL MATRIX COMPOSITE (AlSiC)", International Journal of Advanced Engineering Research and Studies E- ISSN2249–8974.

[10] VICKY KUMAR, JITENDRA KUMAR, SUNIL KUMAR, SANDEEP," Study of Wear behaviour of Aluminium Metal Matrix Composite Reinforced with SiC", International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 Volume: 03 Issue: 05 May- 2016 p-ISSN: 2395-0072.

[11] D. SUJAN, Z. OO, M. E. RAHMAN, M. A. MALEQUE, C. K. TAN "Physio-mechanical Properties of Aluminium Metal Matrix Composites Reinforced with Al2O3 and SiC", International Journal f Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering Vol:6, No:8, 2012.

[12] AMIR HUSSAIN IDRISI, SHAILENDRA DEVA "Development and Testing of Metal Matrix Composite by Reinforcement of Sic Particles on Al 5XXX Series Alloy", International Journal of Engineering Research & Technology, ISSN: 2278-0181 Vol. 3 Issue 2, February – 2014.

[13] ASHOK KR. MISHRA, RAKESH SHEOKAND, DR. R K SRIVASTAVA "Tribological Behaviour of Al 6061/SiC Metal Matrix Composites By Taguchi's Technique", International Journal of Scientific and Research Publications, Volume 2, Issue 10, October 2012, ISSN 2250- 3153.

[14] K.HEMALATHA, V. S. K. VENKATACHALAPATHY, N.ALAGUMURTHY "Processing and Synthesis of Metal Matrix Al 6063/Al2o3 Metal Matrix Composite by Stir Casting Process", Journal of Engineering Research and Applications, ISSN : 2248-9622, Vol. 3, Issue 6, Nov-Dec 2013, pp.1390-1394.

[15] S A MOHAN KRISHNA, T N SHRIDHAR, L KRISHNAMURTHY "Research Significance, Applications And Fabrication Of Hybrid Metal Matrix Composites", International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 5, May 2015, ISSN 2348-7968.

[16] MD. HABIBUR RAHMAN, H. M. MAMUN AL RASHED "Characterization of silicon carbide reinforced aluminum matrix composites", 10th International Conference on Mechanical Engineering, ICME 2013.

[17] MANOJ KUMAR PAL, ARNAV VIKRAM, HIMANSHU PANDEY, ARKA GHOSH "FABRICATION AND COMPARATIVE STUDY OF Zn-Ni METAL MATRIX COMPOSITE", International Journal of Science, Technology & Management, Volume No 04, Special Issue No. 01, May 2015.

[18] SHUBHRANSHU BANSAL, J. S. SAINI "Mechanical and Wear Properties of SiC/Graphite Reinforced Al359 Alloy-based Metal Matrix Composite", Defence Science Journal, Vol. 65, No. 4, July 2015, pp. 330-338.

[19] M. MABUCHI, K.HIGASHI, K. INOUE, S. TANIMURA "EXPERIMENTAL INVESTIGATION OF SUPERPLASTIC BEHAVIOR IN A 20 VOL % SizN4p/5052 ALUMINUM COMPOSITE", Scripta METALLURGICA Vol. 26, pp. 1839-1844, 1992.

[20] A. DOLATKHAH , P. GOLBABAEI, M.K. BESHARATI GIVI, F. MOLAIEKIYA "Investigating effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing", Materials and Design 37 (2012) 458–464.

[21] N. KUMAR, R.K. GAUTAM, S. MOHAN "Wear and Friction Behavior of in-situ AA5052/ZrB2Composites under Dry Sliding Conditions", Vol. 37, No. 2 (2015) 244-256.

[22] FENG TANG, XIAOLING WU, SHIRONG GE, JICHUN YE, HUA ZHU, MASUO HAGIWARA, JULIE M. SCHOENUNG "Dry sliding friction and wear properties of B4C particulate-reinforced Al-5083 matrix composites", Volume 264, Issues 7–8, 15 March 2008, Pages 555–561, www.sciencedirect.com.

[23] ALI ALIZADEH, ALIREZA ABDOLLAHI A. Alizadeh, A. Abdollahi, "Creep Behavior and Wear Resistance of Al 5083 Based Hybrid Composites Reinforced with Carbon Nanotubes (CNTs) and Boron Carbide (B4C)", Journal of Alloys and Compounds (2015), doi: 10.1016/j.jallcom.2015.07.214.

[24] ABHILASH A, DR. PRABHAKAR KAMMAR "Assessment of Mechanical and Corrosion properties of Aluminium Reinforced with Fly Ash (ALFA) Metal Matrix Composites", IJEDR, Volume 4, Issue 3 ISSN: 2321-9939.

[25] TUSHAR SONI, S MANISH1, V.K. HARSHAVARDHAN, SANDEEP RAMINI, RUDRANAIK M, AVINASH L, MURALIDHAR AVVARI "Development of Aluminium Based Hybrid (AA5083/FLYASH/SiCp) MMCs for Ship Building Applications", 5th World Conference on Applied Sciences, Engineering & Technology 02-04 June 2016, HCMUT, Vietnam.

[26] SENTHILKUMAR T S, SENTHIL KUMAR S "EVALUATION OF HARDNESS TEST OF SILICON CARBIDE PARTICULATED ALUMINIUM METAL MATRIX COMPOSITES", INTERNATIONAL JOURNAL OF RESEARCH IN COMPUTER APPLICATIONS AND ROBOTICS ISSN 2320-7345.

[27] BYUNG-WOOK AHN, DON-HYUN CHOI, YONG-HWAN KIM, SEUNG-BOO JUNG "Fabrication of SiCp/AA5083 composite via friction stir welding", Trans. Nonferrous Met. Soc. China 22(2012) s634−s638.

[28] SOURABH GARGATTE, RAHUL R. UPADHYE, VENKATESH S. DANDAGI, SRIKANTH R. DESAI, BHIMAPPA S. WAGHAMODE "Preparation & Characterization of Al-5083 Alloy Composites", Journal of Minerals and Materials Characterization and Engineering, 2013, 1, 8-14.

[29] Meijuan Li, Kaka Ma, Lin Jiang, Hanry Yang, Enrique J. Lavernia, Lianmeng Zhang and Julie M. Schoenung, "Synthesis and mechanical behavior of nanostructured al 5083/ n-TiB2 metal matrix

composites", Materials Science & Engineering A, http://dx.doi.org/10.1016/j.msea.2016.01.031

[30] YONG LI, TERENCE G. LANGDON "CREEP BEHAVIOR OF AN Al-6061 METAL MATRIX COMPOSITE REINFORCED WITH ALUMINA PARTICULATES", Acta mater. Vol. 45, No. 11, pp. 4797-4806, 19970 1997 Acta Metallurgica Inc.

[31] HAMID REZA EZATPOUR, SEYED ABOLKARIM SAJJADI, MOHSEN HADDAD SABZEVAR, YIZHONG HUANG "Investigation of microstructure and mechanical properties of Al6061-nanocomposite fabricated by stir casting", Materials and Design 55 (2014) 921–928.

[32] P.MAHESWARAN, C.J.THOMAS RENALD "Investigation on Wear Behaviour of Al6061-Al2o3-Graphite Hybrid Metal Matrix Composites using Artificial Neural Network", International Journal of Current Engineering and Technology E-ISSN 2277 – 4106, P-ISSN 2347 – 5161.

[33] A. G. WANG, I. M. HUTCHINGS "Wear of alumina fibre-aluminium metal matrix composites by two-body abrasion", Material Science and Technology, Volume 5, 1989-Issue-1.

[34] T. G. NIEH, R. F. KARLAK "AGING CHARACTERISTICS OF B4C-REINFORCED 6061-ALUMINUM", Scripta METALLURGICA Vol. 18, pp. 25-28, 1984.

[35] K. KALAISELVAN, N. MURUGAN, SIVA PARAMESWARAN "Production and characterization of AA6061–B4C stir cast composite", Materials and Design 32 (2011) 4004– 4009.

[36] T. NAKAMURA, S. SURESH "EFFECTS OF THERMAL RESIDUAL STRESSES AND FIBER PACKING ON DEFORMATION OF METAL-MATRIX COMPOSITES", Acta metall, mater. Vol. 41, No. 6, pp. 1665-1681, 1993 0956-7151/93.

[37] B. G. PARK, A. G. CROSKY, A. K. HELLIER "Material characterisation and mechanical properties of Al2O3-Al metal matrix composites", JOURNAL OF MATERIALS SCIENCE 36 (2001) 2417 – 2426.

[38] R.M. WANG, M.K. SURAPPA, C.H. TAO, C.Z. LI, M.G. YAN "Microstructure and interface structure studies of SiCp-reinforced Al (6061) metal-matrix composites", Materials Science and Engineering A254 (1998) 219–226.

[39] S. Nallusamy, A. Karthikeyan "Analysis of Wear Resistance, Cracks and Hardness of Metal Matrix Composites with SiC Additives and Al2O3 as Reinforcement", Indian Journal of Science and Technology, Vol 9(35), DOI: 10.17485/ijst/2016/v9i35/100149, September 2016.

[40] DENISE M. AYLOR, PATRICK J. MORAN "Effect of Reinforcement on the Pitting Behavior of Aluminum-Base Metal Matrix Composites", Journal of Electrochemical Society, 1985 volume 132, issue 6, 1277-1281.

[41] Hasson, D.F., Hoover, S.M. & Crowe, C.R. J Mater Sci (1985) 20: 4147. Doi :10.1007/BF00552410

[42] A. CHENNAKESAVA REDDY, ESSA ZITOUN "Matrix Al-alloys for silicon carbide particle reinforced metal matrix composites", Indian Journal of Science and Technology Vol. 3 No. 12 (Dec 2010) ISSN: 0974- 6846.

[43] MADEVA NAGARAL, V. AURADI, K. I.PARASHIVAMURTHY, S. A. KORI "Wear Behavior of Al2O3 and Graphite Particulates Reinforced Al6061 Alloy Hybrid Composites", American Journal of Materials Science 2015, 5(3C): 25-29 DOI: 10.5923/c.materials.201502.05.

[44] K. UMANATH, K. PALANIKUMAR, S.T. SELVAMANI "Analysis of dry sliding wear behaviour of Al6061/SiC/Al2O3 hybrid metal matrix composites", Composites: Part B 53 (2013) 159–168.

[45] J.B. FOGAGNOLO, M.H. ROBERT, J.M. TORRALBA "Mechanically alloyed AlN particle-reinforced Al-6061 matrix composites: Powder processing, consolidation and mechanical strength

and hardness of the as-extruded materials", Materials Science and Engineering A 426 (2006) 85–94.

[46] T.V. CHRISTY, N. MURUGAN, S. KUMAR "A Comparative Study on the Microstructures and Mechanical Properties of Al 6061 Alloy and the MMC Al 6061/TiB2/12P", Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, pp.57-65, 2010.

[47] S. GOPALAKRISHNAN, N. MURUGAN "Production and wear characterisation of AA 6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method", Composites: Part B 43 (2012) 302–308.

[48] PARDEEP SHARMA, DINESH KHANDUJA, SATPAL SHARMA "Dry sliding wear investigation of Al6082/Gr metal matrix composites by response surface methodology", j m a t e r r e s t e c h n o l . 2 0 1 6;5(1):29–36.

[49] Sharma, P., Sharma, S. & Khanduja, D. Metall and Mat Trans A (2015) 46: 3260. doi:10.1007/s11661-015-2881-9.

[50] SHASHI PRAKASH DWIVEDI, SHAILESH SINGH, HARVEER SINGH PALI "Macrostructure and Mechanical Properties of AA6082/SiC Composite Produced By Mechanical Stir Casting Process", International Conference of Advance Research and Innovation (ICARI- 2014), ISBN 978-93-5156-328-0.

[51] Fu, P.R.K. and Sujan, Debnath and Oo, Zeya and Gotrin, A. and Liew, W.Y.H. 2013. Wear behaviour of Al-SiC and Al-Al2O3 matrix composites sliding against automobile friction material, in Barsourn, B. and Oo, Z. and Habash, R. (ed), The 7th Global Conference on Power Control and Optimization (PCO), Dec 2-3 2013. Yangon, Myanmar: American Institute of Physics.

[52] N.CH. KAUSHIK N, R.N.RAO "The effect of wear parameter sand heat treatment on two body abrasive wear of Al–SiC–Gr hybrid composites", TribologyInternational96(2016)184–190.

[53] ARUMUGAM THANGARASU, RAMASWAMY MOHANKUMAR, NADARAJAN MURUGAN, PERUMALSAMY THANGAPANDI "Processing and characterization of AA6082/TiC composites by stir casting", Emerging Materials Research, ISSN 2046-0147, E- ISSN 2046-0155.

[54] PARDEEP SHARMA, DINESH KHANDUJA, SATPAL SHARMA "Metallurgical and Mechanical characterization of Al 6082- B4C/Si3N4 hybrid composite manufactured by combined ball milling and stir casting", Applied Mechanics and Materials Vols. 592-594 (2014) pp 484-488.

[55] SHAILESH SINGH, SHASHI PRAKASH DWIVEDI, HARVEER SINGH PALI "Wear Characterization of Aa6082/Sic Composite Produced By Mechanical Stir Casting Process", ISTE Delhi Convention Section on "Technological Universities and Institutions in new Knowledge Age : Future Perspective And Action Plan", DTU, SEPTEMBER, 5-6 2013.

[56] Taha, M. A., EL-Sabbagh, A. M., Soliman, M. and Palkowski, H. (2013), Rolling of cast Al-SiCp particulate metal matrix composites and strip mechanical properties. Mat.-wiss. u. Werkstofftech., 44: 914–917.

[57] Hitesh bansal , "wear behaviour of aluminium based metal matrix composites reinforced with red mud,SiC and Al2O3"Department of Mechanical Engineering, M.E. Thesis, Thapar University, Patiala, India, June 2011.

[58] Ravi KR, Sreekumar VM, Pillai RM, Chandan M,Amaranathan KR, Arul KR. Optimization of mixingparameters through a water model for metal matrixcomposites synthesis. Mater Des 2007;28:871–81.

[59] Shorowordi KM, Laoui T, Haseeb ASMA, Celis JP, Froyen L.Microstructure and interface characteristics of B4C, SiC, andAl2O3reinforced Al matrix composites: a comparative study.J Mater Process Technol 2003;142:738–43.

[60] Kerti I, Toptan F. Microstructural variations in castB4C-reinforced aluminium matrix composites (AMCs). MaterLett 2008;62:1215–8.