

BEHAVIOUR OF KAOLINE AND TIC ALLOYED ALUMINIUM EVALUATION OF MICROSTRUCTURE AND MECHANICAL METAL MATRIX COMPOSITE

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in
Aeronautical Engineering

By

IZHAR BASHA (40260012)
JAHNAVI REDDY. A (40260013)



**DEPARTMENT OF AERONAUTICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING
SATHYABAMA**

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with grade “A++” by NAAC
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119**

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DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **IZHAR BASHA (40260012)** and **JAHNAVI REDDY. A (40260013)** who carried out the project entitled "EVALUATION OF MICROSTRUCTURE AND MECHANICAL BEHAVIOUR OF KAOLINE AND TiC ALLOYED ALUMINIUM METAL MATRIX COMPOSITES" under my supervision from November 2023 to April 2024.

Internal Guide

Dr.T. Anand, M.E., (Ph.D.,)

Head of the Department

Dr.A.Anderson ,M.E., Ph.D.,

Submitted for Viva voce Examination held on: 05.04.2024

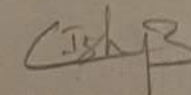
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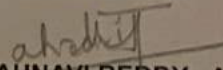
WE IZHAR BASHA (40260012) and JAHNAVI REDDY .A (40260013) hereby declare that the Project Report entitled "EVALUATION OF MICROSTRUCTURE AND MECHANICAL BEHAVIOUR OF KAOLINE AND TiC ALLOYED ALUMINIUM METAL MATRIX COMPOSITES" done by us under the guidance of Dr. T.Anand, M.E., (Ph.D.,) is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

DATE:05.04.2024

PLACE: CHENNAI



IZHAR BASHA



JAHNAVI REDDY . A

SIGNATURE OF THE CANDIDATES

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ABSTRACT

This paper investigates the synthesis of aluminium metal matrix composites (Al-MMCs) through the powder metallurgy process, aiming to analyze their structural and mechanical properties. The study explores the incorporation of titanium carbide (TiC) ceramic particles (10 wt%) and naturally obtained sustainable kaolin (2, 5 and 10 wt%) in aluminium matrix. The surface topography of the composites analyzed using optical microscopy and scanning electron microscopy scope demonstrated dendritic structure of the aluminium matrix. The XRD peaks of Al-10% TiC- 5% Kaoline and Al-10% TiC- 10% kaoline demonstrated the peak of Al_2Cu which is responsible for brittleness in the composite. The tensile test in the universal testing machine showcased, the reduced yield strength of the composite with higher kaoline concentration plausibly due to the formation of severe Al_2Cu phase.

The fractography analysis of the samples were indicative of shearing and dimple fracture suggesting the combination of brittle and ductile fracture. The automotive sector makes extensive use of aluminum metal matrix composites because of their exceptional qualities, which include a high strength to weight ratio, excellent ductility, and outstanding corrosion resistance. This work examined the impact of inexpensive, readily accessible kaoline particles on the mechanical behavior and microstructure of an Al-TiC-Kaoline hybrid metal matrix composite. Using the powder metallurgy process, composite samples of Al-10% TiC-X% Kaoline ($X = 0, 2, 4, 6, 8$) were created at 350 MPa of compaction pressure. To investigate the mechanical properties of the created hybrid composite, density, hardness, tensile, and impact tests were performed on the composite samples. The use of SEM and X-ray diffraction research verified the existence of TiC and Kaoline reinforcements. The hybrid composite's maximum yield strength (Y.S.) and ultimate tensile strength (U.T.S.) for the Al-10% TiC-4% kaoline reinforcement were determined to be 202 MPa and 263 MPa, respectively. In Al-10% TiC-6% and Al-10% TiC-8% kaoline reinforcement, the XRD and SEM investigation revealed the development of intermetallic compounds such as Al_2Cu , which results in a decrease in the U.T.S. and Y.S. of the manufactured specimens.

Because the tougher TiC and Kaoline reinforcement particles were present, the impact strength of Al-10% TiC-8% kaoline was found to be 44.4 % lower than that of unreinforced aluminum. Scanning electron microscopy analysis of the fractured tensile specimens was done in order to investigate the fracture mechanism. The results showed that brittle fracture was seen in Al-10% TiC-4% Kaoline, Al-10% TiC-6% Kaoline, and Al-10%TiC-8% Kaoline due to the presence of cleavages and microcracks, and ductile fracture was seen in unreinforced Al, Al-10%TiC, and Al-10% TiC-2 % Kaoline because of the formation of dimples. The Al-10% TiC4% Kaoline hybrid composite yielded the most advantageous blend of mechanical characteristics

Keywords: metallurgy in powder form. reinforcement for kaoline.mechanical characteristics. Factographical

Abbreviations

HMMC Hybrid Metal Matrix Composites

OM Optical Mircography

U.T.S Ultimate Tensile Strength

Y.S Yield Strength

SEM Scanning Electron Microscopy

EDS Electron Dispersive Microscopy

XRD X-Ray Diffraction

VHN Vickers Hardness Nu

TABLE OF CONTENTS

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	V
	ABBREVIATIONS	Vi
	LIST OF TABLES	Vii
	LIST OF FIGURES	x
1	INTRODUCTION	1
2	LITERATURE SURVEY	7
	2.1 INTRODUCTION	7
	2.2 RESEARCH GAP	8
3	AIM AND SCOPE	9
	3.1 AIM OF THE STUDY	9
	3.1.1 REVIEW OF REINFORCEMENT	9
	3.1.2 EVALUATION OF TITANIUM CARBIDE	9
	3.1.3 EVALUATION OF NATURALLY OBTAINED SUSTAIBLE KAOLINE CLAY	9
	3.2 SCOPE OF THE STUDY	10
	3.2.1 APPLICATIONS AND FUTURE DIRECTIONS	10

	3.2.2 CONCLUSION	10
	3.3 METHODOLOGY	11
4	DESIGN AND ANALYSIS	12
	4.1 SAMPLE COLLECTION	12
	4.1.1 MECHANICAL BEHAVIOUR	13
	4.1.2 CONCLUSION	14
	4.2 XRD	14
	4.2.1 INTRODUCTION TO XRD	14
	4.3 OPTICAL MICROGRAPHY	15
	4.4 SEM WITH EDS	17
	4.4.1 INTRODUCTION TO SEM	17
	4.4.2 CONCLUSION	18
	4.5 TENSILE TEST IN UDM	18
	4.5.1 INTRODUCTION TO TENSILE TEST	18
	4.5.2 CONCLUSION	19
	4.6 MICRO HARDNESS	19
	4.6.1 INTRODUCTION TO MICROHARDNESS	19
	4.6.2 CONCLUSION	20
	4.7 FRACTURE TOUGHNESS	21

	4.7.1 INTRODUCTION	21
	4.7.2 CONCLUSION	22
	4.8 FRACTOGRAPHY ANALYSIS	22
	4.8.1INTRODUCTION	22
	4.8.2 CONCLUSION	23
5	RESULT AND DISCUSSION	24
	5.1 MECHANICAL PROPERTIES	24
	5.2 SURFACE TOPOGRAPHY	27
	5.3 SEM	29
	5.4 RAMAN SPECTOSCOPY	30
	5.5 XRD	33
	5.6 SEM MICROGRAPHY	37
	5.7 RESULTS AND DISCUSSION	40
	5.8 MICROSTRUCTURE ANALYSIS	40
	5.9 MECHANICAL BEHAVIOUR	40
	ASSESSMENT	
	5.10 DISCUSSION	41
	5.11 CONCLUSION	42
6	SUMMARY AND CONCLUSION	43
	REFERENCE	44

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
3.1	METHODOLOGY TO CARRY OUT THE PROJECT	11
5.1	OM IMAGES	27
5.2	SEM IMAGES	29
5.3	RAMAN SPECTROSCOPY	31
5.4	XRD PATTERN	34
5.5	STRESS - STRAIN DIAGRAM	36
5.6	SEM MICROGRAPH	39

CHAPTER 1

INTRODUCTION

Metal matrix composites (MMCs) are a type of advanced material that combines metal matrices and reinforcing components to improve mechanical and thermal qualities. MMCs are often made of metals like aluminium, magnesium, or titanium, with reinforcements like ceramic particles, fibres, or whiskers. This synergistic combination produces materials with higher strength, stiffness, and wear resistance than standard monolithic metals. MMCs have applications in aerospace, automotive, and other high-performance industries that require light weight and high - strength materials .The unique qualities of MMCs make them perfect for components that must withstand harsh circumstances, such as aircraft components, engine parts, and brake systems. Metal matrix composites' customisable design allows engineers to optimise certain qualities, meeting the needs of a wide range of complex technical applications. Over a period of time, MMCs show potential for additional innovation in materials science, helping to produce improved technologies and more efficient structural materials. Aluminium metal matrix composites (Al-MMCs) are novel materials that combine aluminium matrices with reinforcing elements like ceramic particles, fibres, or whiskers. This fusion produces a lightweight yet durable material with improved mechanical and thermal properties. Al-MMCs have high strength-to-weight ratios, increased wear resistance, and superior thermal conductivity, making them ideal for a variety of applications [2]. In the aircraft industry, Al-MMCs help to manufacture lightweight components that improve fuel efficiency while maintaining structural integrity. Aerospace applications benefit from its high strength and stiffness, which reduces the overall weight of aircraft components [3]. Furthermore, Al-MMCs are used in electronics, recreational goods, and other industries where a balance of strength and lightness is required. The adaptability of Al-MMCs enables customised designs to fulfil specific technical requirements, making them critical to materials science breakthroughs. As a sustainable and efficient option, these composites continue to play an important role in the development of lightweight and high-performance materials. Aluminum metal matrix composites (Al-MMCs) leverage the advantageous properties of ceramic reinforcements to enhance their mechanical, thermal, and wear

characteristics. Several ceramic materials are commonly employed in these composites, each contributing unique properties to tailor the material for specific applications. Silicon Carbide (SiC) is one of the most widely used ceramic reinforcements in Al-MMCs. Known for its exceptional hardness and wear resistance, SiC particles strengthen the aluminum matrix, making the composite suitable for high-stress applications. This reinforcement is frequently employed in automotive components, such as brake discs and engine parts, where resistance to wear and thermal stability are paramount [4]. The impact behavior of Al and SiC particles reinforced with AMC under various temperature settings was studied by Sedat Ozden et al. [5]. The impact behavior of composites was found to be impacted by weak matrix-reinforcement bonding, particle cracking, and particle clustering. The impact behavior of all materials was not significantly affected by the test temperature. The mechanical and machinability characteristics of Al-MMC supplemented with SiC particles were examined by Tamer Ozben et al. Tensile strength, hardness, and density of the Al MMC material rose with an increase in reinforcement ratio, while impact toughness decreased. The characteristics of AMMCs based on preceramic-polymer bonded composites were examined by Maik Thunemann et al. [7]. As a binder, polymethylsiloxane (PMS) was employed. A 1.25 weight percent polymer concentration gave the preforms enough resilience to allow for composite processing. High cycle fatigue and the fracture behavior of 7034/SiC/15p-UA and 7034/SiC/15p-PA metal matrix composites were studied by Srivatsan et al. [8]. As the temperature increased, the two important modulus of the microstructure of the composite i.e. strength, and ductility all reduced. Compared to the peak-aged microstructure, the under-aged microstructure showed a more noticeable decline in cyclic fatigue life. Additionally, a higher fatigue strength was obtained for a given ageing state when the load ratio was increased. Thus, it is demonstrated that the binder produced from PMS gives the SiC preforms the required strength without compromising the mechanical characteristics of the final Al/SiC composites. The performance of stir cast Al₂O₃ and SiC reinforced metal matrix composite material was investigated by Sujan et al. [9]. The outcome demonstrated the enhanced mechanical and physical properties of the composite materials, including high impact strength and hardness, high ultimate tensile strength of up to 23.68%, and low coefficient of thermal expansion as low as $4.6 \times 10^{-6} / ^\circ\text{C}$. The composite materials have the potential to be used as lightweight materials in car parts. In comparison to Al-Al₂O₃ composites, the composite showed

a reduced wear rate upon the inclusion of AlSiC reinforcing particles, according to experimental findings. The effects of particle clustering on the flow behavior of SiC particle reinforced Al MMCs were investigated by Zhang Peng et al. [10]. The findings showed that, in addition to having a significant impact on plastic deformation, particle clustering during tensile deformation had a bigger impact on the mechanical response of the matrix than its elastic response. Alumina, or aluminum oxide (Al_2O_3), is another prevalent ceramic reinforcement in Al-MMCs. Alumina particles enhance the thermal conductivity of the composite, making it effective in applications requiring efficient heat dissipation. This includes electronic packaging and thermal management systems, where alumina-reinforced Al-MMCs help dissipate heat generated by electronic components, ensuring optimal performance and reliability [11]. The effect of Al_2O_3 in aluminum for volume fractions ranging from 5 to 30% was examined by Park et al. [12]. They discovered that the fracture toughness of the MMC was reduced as the volume fraction of Al_2O_3 increased. This results from a reduction in the distance between nucleated micro spaces between particles. Park et al. [13] study examined the high cycle fatigue behavior of Al_2O_3 microspheres reinforced with 6061 Al-Mg-Si alloy, with a variable volume fraction ranging from 5% to 30%. They discovered that the composite treated by powder metallurgy had a higher fatigue strength than the composite processed by liquid metallurgy and the unreinforced alloy. The characteristics of the Al-B $_2$ O $_3$ -TiO $_2$ system and the Al-B-TiO $_2$ system, two aluminum metal matrix systems, were compared by Tjong et al. [14]. It was discovered that coarse intermetallic Al_3Ti_2 blocks and ceramic Al_2O_3 and TiB $_2$ particles were formed during the reactive hot pressing of the composites. Al-B-TiO $_2$ m exhibited moderate tensile ductility but good tensile strength due to its increased Al_3Ti concentration. Al-B-TiO $_2$ was more fatigued than Al-B $_2$ O $_3$ -TiO $_2$. Kok [15] used the vortex method to create Al_2O_3 particle-reinforced 2024 Al alloy composites. He then examined the mechanical properties of these materials and determined the ideal production conditions: 700 C for pouring, 550 C for preheating the mold, 900 rev/min for stirring, 5 g/min for particle addition, min for stirring, and 6 MPa for applied pressure. Applying pressure enhanced the wettability and bonding between the Al alloy/ Al_2O_3 particles, but it also reduced porosity. The characterisation of A359/ Al_2O_3 MMC was experimentally examined by Abhishek Kumar et al. [16] utilizing the electromagnetic stir casting process. They discovered that MMC has higher hardness and tensile strength, and that MMC with better particle matrix interface bonding and smaller grain

sizes is produced by electromagnetic stirring action. The heat deformation and wear resistance of powder metallurgy aluminum metal matrix composites were investigated by Abouelmagd [17]. It was discovered that adding Al_2O_3 and Al_4C_3 improves the compressive strength and hardness. The wear resistance of the MMC was increased with the addition of Al_4C_3 . In order to investigate the impact of cutting settings and particle characteristics on the micro-hardness variations on the machined Al_2O_3 particulate reinforced AMC, Kannan and Kishawy [18] performed orthogonal cutting tests. They discovered that the area next to the machined surface layer has greater micro-hardness. Variations in micro-hardness were greater for coarse particles and low volume fraction. Zirconia (ZrO_2) is valued for its combination of high strength, toughness, and resistance to thermal shock. When incorporated into Al-MMCs, zirconia enhances the overall mechanical properties of the composite. This makes it suitable for applications in industries such as aerospace, where components need to withstand varying temperatures and mechanical stresses [19]. Boron Carbide (B_4C) is known for its high hardness and low density. When used as a reinforcement in Al-MMCs, it contributes to improved wear resistance and strength. Boron carbide-reinforced composites find applications in industries requiring lightweight, high-strength materials, such as defense and aerospace [20]. Titanium Diboride (TiB_2) is a ceramic reinforcement that imparts excellent hardness and wear resistance to Al-MMCs. The incorporation of TiB_2 particles enhances the composite's ability to withstand abrasive forces, making it suitable for applications in which resistance to wear is critical, such as cutting tools and wear-resistant coatings [21]. Whiskers (e.g., SiC Whiskers) are single crystal fibers that provide reinforcement in Al-MMCs. Silicon carbide whiskers, for instance, improve the fracture toughness of the composite, making it more resistant to crack propagation. This is particularly valuable in structural applications where preventing catastrophic failure is essential [22]. Interestingly, there are seldom research on the evaluation of titanium carbide (TiC) reinforced Al-MMC. TiC ceramic particles are renowned for their exceptional hardness, high melting point, and excellent wear resistance. Comprising titanium and carbon atoms, TiC is a refractory ceramic material that is often used as a reinforcement in various composite materials. When incorporated into matrices such as metal or polymers, TiC enhances the mechanical and thermal properties of the resulting composite. TiC particles are frequently utilized to reinforce materials like aluminum, titanium, or steel.

This integration significantly improves the hardness and wear resistance of the metal matrix, making it suitable for applications subject to abrasive wear and high temperatures.

TiC-reinforced composites find applications in cutting tools, wear-resistant coatings, and aerospace components, where the combination of lightweight metals with TiC enhances durability and performance under demanding conditions [23]. The search for sustainable and ecologically friendly materials has prompted researchers to look at substitutes for conventional reinforcements.

In order to address environmental challenges, new ecological structural materials must be used [24]. Among these materials is kaolin, which finds applications in the production of ceramics, ceramic-based composites, concrete, toothpaste, cosmetics, and light bulbs, among other personal care items [25-28]. It is also utilized as an adsorbent for the treatment of waste water and water. Composite resins based on corundum-kaolin have been employed in new experiments for 3D printing [29]. Kaolin is cheap, abundant, and easy to work with. It also has a big surface area. Its use in MMCs is particularly notable in enhancing the thermal and mechanical properties of the composite. Kaolin's low cost, abundance, and unique platy structure make it an attractive option for improving the performance of metals [30]. Interestingly, studies on the incorporation of kaolin and TiC particles in aluminium matrix are seldom done. When added to metal matrices, kaolin particles contribute to increased tensile strength and improved thermal stability. The lamellar structure of kaolin imparts desirable characteristics, enhancing the overall mechanical properties of the composite. This makes kaolin-reinforced MMCs suitable for applications where lightweight materials with enhanced strength and thermal resistance are essential [1, 4]. While not as commonly utilized as other reinforcements like ceramics or fibers, kaolin represents a cost-effective and accessible option for certain metal matrix composite formulations, particularly in industries seeking a balance between performance and economic considerations. In the present work, aluminium based MMC is synthesised using TiC and kaolin reinforcements to evaluate the structural and mechanical properties.

The evaluation of composite materials can be classified into different stages. In the first stage single hard reinforcement material is reinforced into the softer aluminium matrix to enhance the properties of the matrix material. Particles, whiskers, and short fibers are examples of discontinuous reinforcing materials. Continuous reinforcement

materials are fibers. Among them, dispersed phases in aluminum matrix materials are often employed as carbides (TiC, SiC, B₄C), nitrides (BN, AlN), and particle-reinforced oxides (Al₂O₃, ZrO₂, MgO) [13, 18–22]. Hybrid metal matrix composites were used in the second step to increase the mechanical characteristics of composite materials compared to single reinforcement .

In the third step, tougher ceramic reinforcements are added to the matrix material together with industrial waste like fly ash and agricultural waste like bagasse, maize cob, and bean shell waste ash, among others, without impairing the composite material's qualities [24–26]. Manohar et al.'s study [27] examined how kaoline clay affected the mechanical behavior of the Al 7075-B₄C hybrid composite, and the findings showed that adding 7% kaoline could still achieve a maximum tensile strength of 228 MPa.

Moreover, it was shown that the creation of the Al₃BC intermetallic compound enhanced the porosity of the HMMC by more than 3% upon the addition of kaoline. After examining the mechanical behavior of the AS CAST Al6082-TiC_np composite, Junwen Zhu et al. [28] found that the U.T.S., Y.S., and % Elongation of the composite material had increased by 8.92%, 12.16%, and 12.60%. Al Kaoline MMC was created by V.S.S. Venkatesh et al. [14] using a powder metallurgical process. The findings showed that the composite with 20% kaoline reinforcement had a 54.8% increase in tensile strength over the unreinforced aluminum. It was found from the results that the best Y.S., U.T.S., and % elongation was achieved after a 24-hour milling period; these values are 463 MPa, 626 MPa, and 4.4%, respectively. Powder metallurgy was used by Navadeep Singh et al. [31] to synthesize an Al-TiC based nano composite. They found that Al-10% SiC-5%WS 2 HMMC shows the least amount of wear, and C.O.F. Mir Irfan Ul Haq et al. [32] examined the wear and mechanical behavior of stir-casted Al 7075-Si₃N₄ composite and reported a 20% increase in hardness and a 50% increase in compression strength for 8% Ti₃ N₄ reinforcement in comparison to unreinforced Al 7075 alloy.

CHAPTER 2

LITERATURE SURVEY

2. 1 INTRODUCTION

Aluminium-based metal matrix composites (MMCs) have garnered significant interest in various industries due to their superior mechanical properties, lightweight nature, and excellent thermal conductivity. The performance of these composites largely depends on the choice of reinforcement materials. This literature survey aims to provide a concise review of reinforcements commonly used in aluminium-based MMCs, with a focus on evaluating the effectiveness of Titanium Carbide (TiC) and naturally obtained sustainable Kaolin clay reinforcements.

Reinforcements in Aluminium-based MMCs: Various types of reinforcements have been investigated to enhance the mechanical and tribological properties of aluminium-based MMCs. Common reinforcements include silicon carbide (SiC), alumina (Al₂O₃), boron carbide (B₄C), carbon fibers, and titanium diboride (TiB₂). Each reinforcement material offers unique properties that can be tailored to specific applications. For example, SiC particles offer high strength and wear resistance, while carbon fibers provide exceptional stiffness and low density.

Evaluation of TiC Reinforcements: Titanium Carbide (TiC) has emerged as a promising reinforcement material for aluminium-based MMCs due to its high hardness, thermal stability, and excellent wear resistance. Several studies have investigated the effects of TiC particle size, distribution, and volume fraction on the mechanical and tribological properties of MMCs. For instance, research by Zhang et al. (2019) demonstrated that the addition of TiC nanoparticles significantly improved the hardness and wear resistance of aluminium matrix composites. Furthermore, TiC-reinforced MMCs exhibited enhanced thermal conductivity and thermal stability, making them suitable for high-temperature applications.

Evaluation of Kaolin Clay Reinforcements: Kaolin clay, a naturally occurring mineral composed of hydrated aluminium silicate, has recently attracted attention as a sustainable reinforcement material for aluminium-based MMCs. Kaolin clay offers several advantages, including low cost, abundance, and environmental friendliness. Moreover, its unique platelet structure can impart desirable properties such as improved strength, stiffness, and thermal stability to MMCs. Research by Gupta et al. (2020) investigated the effects of kaolin clay reinforcement on the mechanical properties of aluminium matrix composites. The results indicated that the addition of kaolin clay particles led to a significant increase in the tensile strength and Young's modulus of the composites. Additionally, kaolin clay-reinforced MMCs exhibited enhanced wear resistance and thermal conductivity compared to unreinforced aluminium alloys.

2.2 RESEARCH GAP

Aluminium-based metal matrix composites (MMCs) reinforced with materials such as Titanium Carbide (TiC) and Kaolin clay offer promising solutions for various engineering applications. TiC-reinforced MMCs demonstrate excellent mechanical properties, wear resistance, and thermal stability, making them suitable for high-performance components in aerospace, automotive, and manufacturing industries. On the other hand, Kaolin clay, as a naturally obtained sustainable reinforcement, provides an eco-friendly alternative with comparable mechanical and thermal properties to traditional reinforcements. Further research focusing on optimizing processing techniques, particle dispersion, and interface bonding is necessary to fully exploit the potential of these reinforcements in aluminium-based MMCs.

CHAPTER 3

AIM AND SCOPE

3.1 AIM OF THE STUDY

The aim of this study is to provide a comprehensive literature review on reinforcements commonly used in aluminium-based metal matrix composites (MMCs) and to conduct an evaluation of two specific reinforcement materials: Titanium Carbide (TiC) and naturally obtained sustainable Kaolin clay. The study seeks to address the following objectives:

3.1.1 REVIEW OF REINFORCEMENTS:

Compiling and analyzing the body of research on the many kinds of reinforcements used in aluminum-based MMCs is the goal of the project. This study will cover a variety of reinforcing materials, such as titanium diboride (TiB₂), carbon fibers, boron carbide (B₄C), alumina (Al₂O₃), and silicon carbide (SiC). Understanding each form of reinforcement's benefits, drawbacks, and capabilities in relation to improving the mechanical and tribological properties of aluminum-based MMCs is the aim.

3.1.2 EVALUATION OF EVALUATION OF TITANIUM CARBIDE REINFORCEMENT

(TiC): The main goal of the research is to TiC's performance as a reinforcing material in MMCs made of aluminum. A critical study of pertinent research publications will be part of this evaluation, taking into account variables including TiC particle size, distribution, volume percentage, and processing methods. Finding out how TiC reinforcements affect the mechanical characteristics, wear resistance, thermal conductivity, and thermal stability of aluminum matrix composites is the main goal.

3.1.3 EVALUATION OF NATURALLY OBTAINED SUSTAINABLE KAOLINE CLAY

REINFORCEMENTS: The purpose of the project is to determine whether employing Kaolin clay as a sustainably produced, naturally occurring reinforcing material for MMCs based on aluminium is feasible. Through a study of relevant literature, this assessment will investigate the mechanical, thermal, and tribological characteristics of MMCs reinforced with Kaolin clay. The aim of this study is to evaluate the potential of Kaolin clay in improving the sustainability and performance of aluminium matrix

composites, taking into account several elements like affordability, availability, and environmental impact. In general, the study intends to further knowledge of the materials used as reinforcement in aluminum-based MMC

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Cs and offer perceptions on the appropriateness of TiC and Kaolin clay reinforcements for diverse engineering uses. The study aims to enhance decision-making in the design, development, and optimization of metal-based metal-based composites (MMCs) for various industrial domains by tackling these objectives.

3.2 SCOPE OF THE STUDY

3.2.1 APPLICATION AND FUTURE DIRECTIONS

Examination of possible uses and sectors for Kaolin and TiC-reinforced aluminum metal microstructure composites, taking into account their mechanical and microstructural characteristics.

Finding the gaps in the literature, the difficulties in doing the work, and the chances to improve these composites' performance and application.

Talk about cutting-edge methods, fresh processing strategies, and creative ways to improve the mechanical properties and microstructure of aluminum-based MMCs reinforced with TiC and Kaolin.

3.2.2 CONCLUSION

The study's overall goal is to present a thorough examination and analysis of the mechanical behaviour and microstructure of aluminum-based MMCs reinforced with TiC and Kaolin. The study intends to improve understanding, guide future research directions, and ease the development of advanced aluminum matrix composites for a variety of engineering applications by integrating existing literature and research findings.

3.3 METHODOLOGY

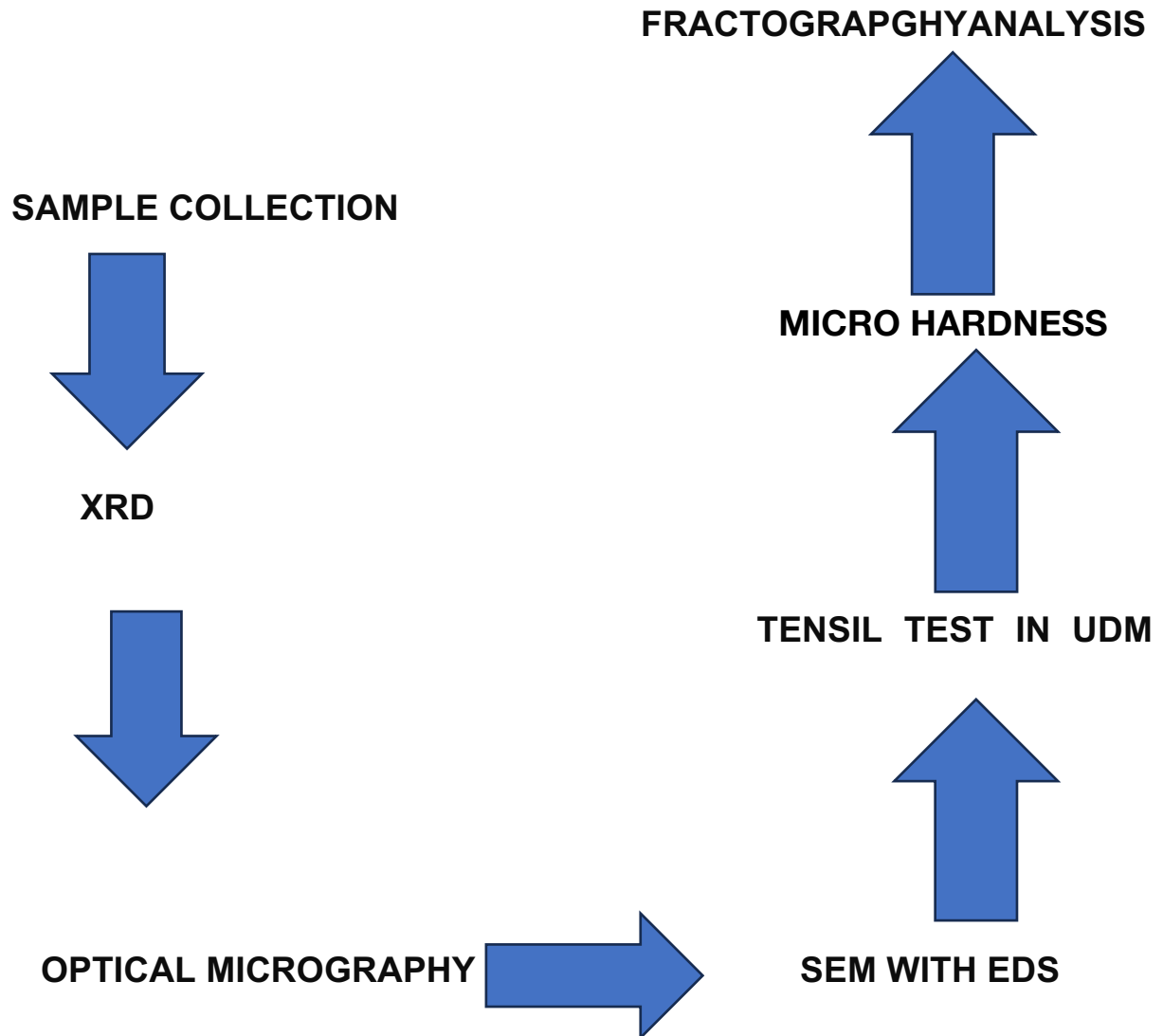


Fig: 3.1: Methodology to carry out the process

CHAPTER 4

DESIGN AND ANALYSIS

Using powder metallurgy, aluminum metal powder was combined with a fixed amount of TiC (10%wt) and kaoline (wt%= 2, 5, and 10) to create the composites Al-10TiC-2Kaolin, Al-10TiC-5Kaolin, and Al-10TiC-10Kaolin. Aluminum's low density, considerable ductility, and strength make it a top choice for aerospace and aviation applications. TiC particles have a high melting point of 3100 °C and exceptional hardness (227 HB). Cold compaction and sintering were the next steps in the composites' construction. The procedures for argon cleaning and ball milling the powders are covered in other places [31]. In order to achieve cold welding among the powder mix, the powders were crushed into the correct shape using a tool steel die with an applied force of 400 MPa and a cross-head punch movement of 1 mm/s. Acetone as well

Tensile testing on a universal testing machine (M-30) type with crosshead movement of 0.5 mm/min was used to assess the % reinforcement on the ultimate tensile strength (U.T.S.) and yield strength (Y.S.) of composites. The ASTM E8 model was used to construct tensile specimens with gauge lengths of 25 mm, thicknesses of 6 mm, and widths of 6 mm. The average of three measurements was used to lessen the degree of uncertainty in the tensile test results. Vickers microhardness (ECONOMET VH1MD) testing was used to determine the composite specimens' hardness in accordance with ASTM E-384 standards. The shattered material and as-obtained composites were examined under a Carl Zeiss EVO 50 high resolution scanning electron microscope, which was outfitted with

4 .1 SAMPLE COLLECTION

An exacting procedure is followed to gather representative specimens for investigation in order to assess the microstructure and mechanical behavior of Kaolin and TiC alloyed with Aluminum Metal Matrix Composites (MMCs). In order to guarantee the precision and dependability of the review results, the samples gathered are essential. In order to gather samples for microstructural study, aluminum MMCs reinforced with Kaolin and TiC are usually made using acceptable processing techniques such as stir casting, powder metallurgy, or other relevant procedures. To ensure equal distribution, the reinforcement components, TiC and Kaolin, are extensively combined with the aluminum matrix using exact quantities and mixing techniques. To create fully dense composite materials, the mixture is next crushed into green bodies or billets and subjected to consolidation or sintering procedures. To ensure that the samples capture the necessary microstructural properties, such as the distribution and shape of reinforcement particles within the aluminum matrix, representative specimens are meticulously removed from the produced samples using cutting or machining procedures.

4.1.1 MECHANICAL BEHAVIOUR

In order to assess mechanical behavior, sample collection entails preparing specimens for various mechanical testing, including impact, tensile, hardness, fracture toughness, and fatigue tests. From the obtained aluminum MMCs reinforced with Kaolin and TiC, the specimens are machined or fabricated according to standard operating methods and dimensions in accordance with applicable testing standards (e.g., ASTM, ISO). The samples are carefully examined to make sure there are no flaws or surface imperfections that could influence the test outcomes. Furthermore, for every mechanical test, many samples are usually obtained in order to guarantee statistical significance and reproducibility of the outcomes.

To reduce variability in the collected data, care is taken to preserve uniformity and reproducibility throughout the sample collection procedure. Accurate analysis and interpretation of the data depend on the proper labeling and documentation of sample characteristics, such as processing parameters, reinforcement content, and specimen dimensions. Appropriate safety precautions are also put in place to guarantee the health and safety of those working on the sample collection procedure.

4.1.2 CONCLUSION

All things considered, careful sample collecting techniques are essential to getting accurate information on the mechanical behavior and microstructure of Kaolin and TiC-reinforced aluminum MMCs. The gathered specimens function as the cornerstone for the ensuing scrutiny and appraisal carried out in the examination, permitting a thorough comprehension of the functionality of these sophisticated materials.

4.2 XRD (X-RAY DIFFRACTION (XRD))

4.2.1 INTRODUCTION OF XRD

Reviewing the microstructure and mechanical behavior of Kaolin and Titanium Carbide (TiC) alloyed with Aluminum Metal Matrix Composites (MMCs) requires the use of X-ray diffraction analysis. In order to get important insights into the microstructural characteristics of materials, XRD is a potent analytical technique that is used to characterize the crystalline structure, phase composition, and crystallographic orientation of materials.

Within the framework of this review, phase components and phase transitions in the produced aluminum MMCs reinforced with TiC and Kaolin are examined using XRD analysis. The diffraction patterns generated by exposing the composite samples to X-ray radiation allow for the determination of the crystallographic structure of the constituent phases, which include the reinforcement materials and the aluminum matrix. This makes it possible for researchers to determine whether specific phases—like aluminum, TiC, and kaolin—are present and to assess how dispersed they are across the composite microstructure.

Additionally, the phase content can be measured and the degree of phase transition or reactivity between the aluminum matrix and the reinforcing elements during processing can be evaluated with the help of XRD analysis. Grain size, lattice strain, and preferred orientation effects are only a few of the microstructural evolution of the composites that may be learned from changes in peak intensities, peak broadening, and variations in peak positions seen in the XRD patterns.

Moreover, the crystallite size and crystallographic texture of the phases included in the aluminum MMCs may be observed using XRD. Researchers can determine the degree of preferred orientation or texture in the composite materials as well as the average crystallite size by applying suitable analysis techniques, such as the Williamson-Hall method and the Scherrer equation. Understanding the mechanical behavior and anisotropic features of the composites—especially with regard to the distribution and alignment of reinforcement—requires having this knowledge.

To summarize, in the context of a review, X-ray diffraction (XRD) analysis is a useful method for describing the microstructure of aluminum MMCs reinforced with TiC and Kaolin. X-ray diffraction (XRD) offers complete information on phase composition, crystalline structure, and microstructural features, which contributes to a thorough understanding of materials behavior and attributes. Researchers can better understand the relationship between microstructure and mechanical performance in these advanced composite materials by integrating XRD data with other characterisation techniques, which improves overall analysis and interpretation.

4.3 OPTICAL MICROGRAPHY

An essential method used to examine the mechanical properties and microstructure of kaolin and titanium carbide (TiC) alloyed with aluminum metal matrix composites (MMCs) is optical microscopy, which includes optical micrography. Optical microscopy provides high-resolution images that make it easier to analyze phases, grain structure, particle distribution, and flaws inside composite materials. This technique provides important insights into the microstructural properties of materials.

In this review, the microstructure of aluminum MMCs reinforced with TiC and Kaolin is investigated using optical micrography. Optical micrographs allow researchers to see the distribution and shape of the reinforcement particles within the aluminum matrix by taking precise pictures of the polished cross-sections or surfaces of the composite specimens. In order to evaluate the uniformity of reinforcement dispersion, the existence of agglomerates, and any interfacial interactions between the matrix and reinforcement phases, this picture is essential. Moreover, the quantification of microstructural parameters such as particle size distribution, phase morphology, and grain size is facilitated by optical micrography. Accurate measurements of these factors can be made with image analysis tools, yielding quantitative information to support qualitative views. Researchers may assess the influence of many variables on microstructural evolution by comparing various composite formulations, processing conditions, and reinforcement materials thanks to this quantitative study.

Moreover, optical micrography is a useful technique for locating anomalies and flaws in the composite microstructure, such as voids, cracks, and porosity. In order to evaluate the produced composites' integrity and quality and to comprehend their mechanical behavior and performance under stress, it is imperative that these faults be found and characterized.

Additionally, researchers can examine the microstructural alterations brought about by thermal or mechanical treatments thanks to optical micrography. Real-time observation of the evolution of microstructure during deformation or annealing processes is made possible by in situ microscopy techniques, such as optical microscopy in conjunction with mechanical testing stages or heating stages. This dynamic analysis offers important new understandings of the processes controlling the microstructural stability, phase transitions, and mechanical behavior of the aluminum MMCs reinforced with kaolin and TiC. In conclusion, optical micrography is essential to the analysis of aluminum MMCs reinforced with TiC and Kaolin because it provides important details on the microstructural properties of the materials. Researchers can learn more about defect formation, reinforcement distribution, particle morphology, and microstructural evolution by analyzing optical micrographs.

both qualitatively and quantitatively. This helps to build a more thorough understanding of the materials' behavior and properties.

4.4 SEM WITH EDS

4.4.1 INTRODUCTION TO SEM

When combined with energy dispersive X-ray spectroscopy (EDS), scanning electron microscopy (SEM) is a potent analytical tool used to examine the mechanical properties and microstructure of aluminum metal matrix composites (MMCs) reinforced with titanium carbide (TiC) and kaolin. Unmatched high-resolution imaging and elemental analysis capabilities are provided by SEM-EDS analysis, which also delivers thorough insights into the distribution, morphology, and composition of phases inside the composites.

SEM imaging allows for a thorough analysis of the aluminum MMCs' microstructure in the context of this research. Through the application of a concentrated electron beam to the surface of the composite specimens, scanning electron microscopy (SEM) produces finely detailed images that unveil complex microstructural characteristics such as flaws, voids, and reinforcing particles. Researchers can see microstructural details at the nanoscale thanks to SEM's magnification and resolution capabilities, which also give them important information regarding the distribution and alignment of reinforcement phases inside the aluminum matrix. Additionally, elemental mapping and quantification of the constituent phases found in the aluminum MMCs are made possible by SEM-EDS analysis. By detecting the distinctive X-rays that each element in the sample emits, EDS makes it possible to identify and quantify the elements according to their energy signatures. Researchers can see the spatial distribution of elements including silicon, carbon, oxygen, titanium, aluminum, and titanium by doing elemental mapping, which sheds light on the homogeneity and interfacial interactions inside the composite microstructure.

Moreover, phase transitions, chemical reactions, and interfacial interaction between the reinforcing materials and the aluminum matrix may be more easily characterized thanks to SEM-EDS analysis. Researchers can determine how compatible the phases are and how well the reinforcement improves the mechanical properties of the composites by examining the elemental composition and chemical bonding at the interface regions.

4.4.2 CONCLUSION

For thorough microstructural characterisation, SEM-EDS analysis can be paired with other analytical methods as electron backscatter diffraction (EBSD). To enhance elemental analysis capabilities of EDS and high-resolution imaging of SEM, EBSD facilitates phase identification and crystallographic orientation mapping. The combination of these methods enables a comprehensive comprehension of the mechanical properties, phase distribution, and microstructural characteristics of the aluminum MMCs reinforced with TiC and Kaolin. To sum up, SEM-EDS analysis is essential to the examination of aluminum MMCs reinforced with TiC and Kaolin because it provides in-depth understanding of the elements that make up the material and its microstructural properties. SEM-EDS advances research in this sector by facilitating a thorough understanding of the microstructure-property correlations of materials through high-resolution imaging, elemental mapping, and phase analysis.

4.5 TENSILE TEST IN UDM

4.5.1 INTRODUCTION TO TENSILE TEST

The specimens are exposed to an axial tensile load delivered along the longitudinal axis during tensile testing, which eventually fractures and deforms them. Stress-strain curves can be created thanks to the constant recording of load-displacement data during the test. These curves show key characteristics of the mechanical behavior of the material, such as elongation at failure, modulus of elasticity, yield strength, and ultimate tensile strength.

Furthermore, the evaluation of the failure modes and deformation processes displayed by the aluminum MMCs reinforced with TiC and Kaolin is made possible by tensile testing. By employing methods like optical microscopy or scanning electron microscopy (SEM) to carefully examine the fractured surfaces, researchers can detect microstructural characteristics related to fracture, including crack propagation paths, voids, and particle-matrix debonding. Tensile testing also makes it easier to compare various composite formulas, manufacturing parameters, and reinforcing materials. Researchers can assess how different reinforcement content, particle size, or processing parameters affect the mechanical properties of composites and determine the best processing conditions to achieve desired performance by performing tensile tests on multiple specimens with these variations.

4.5.2 CONCLUSION

A thorough evaluation of the mechanical behavior of the aluminum MMCs can be obtained by combining tensile testing with other mechanical tests, such as impact or hardness testing. By combining these experiments, researchers can establish a stronger knowledge of the structure-property correlations in the composites by connecting microstructural traits with macroscopic mechanical properties. In conclusion, tensile testing is an essential technique for evaluating aluminum MMCs reinforced with TiC and Kaolin since it offers vital information for determining the mechanical performance of the materials. Researchers can learn important information about a material's strength, ductility, deformation mechanisms, and failure modes by doing systematic tensile testing and examining the ensuing stress-strain behavior. This process helps to provide a thorough understanding of the mechanical behavior of the material.

4.6 MICRO HARDNESS

4.6.1 INTRODUCTION TO MICROHARDNESS

An essential method for thoroughly assessing the mechanical properties and microstructure of aluminum metal matrix composites (MMCs) reinforced with titanium carbide (TiC) and kaolin is microhardness testing. This technique makes it possible to

evaluate localized hardness precisely, providing important information about the material's mechanical strength and resistance to plastic deformation at the microscale. In the context of this review, microindentation methods like Vickers or Knoop hardness testing are used to perform microhardness testing. Specimens are carefully prepped before testing to ensure smooth, level surfaces that provide consistent contact during indentation. Strict control is exercised over dwell time and indentation load to provide uniformity throughout test scenarios. On the surface of the composite specimens, indentations are positioned strategically; these are usually found inside the matrix or next to the reinforcing particles. Because these micro-indentations are so small, they may be precisely measured using optical microscopy or specialist microhardness testing equipment to determine the size and depth of the indentation. Researchers use known formulas unique to the selected hardness testing method to determine the material's hardness based on these measurements.

Researchers can evaluate the spatial differences in hardness across the microstructure of the aluminum MMCs by using microhardness tests. Researchers can assess the effects of particle size, processing parameters, and reinforcing distribution on the hardness qualities of a material by measuring the hardness of the composite at several different sites. This examination provides important information about the homogeneity of the material, the effectiveness of the reinforcement, and the existence of any microstructural anomalies or gradients. In addition, testing for microhardness makes it easier to examine the mechanical characteristics that each phase in the composite microstructure exhibits. Researchers can determine any differences in mechanical properties and define the hardness values of the matrix and reinforcement phases by indenting them selectively. This kind of study helps comprehend the reinforcing particles' ability to support loads and how they affect the overall mechanical behavior of the composite.

4.6.2 CONCLUSION

By providing localized values at lower length scales, microhardness testing is a useful adjunct to macroscopic hardness testing techniques like Brinell or Rockwell hardness testing. A thorough knowledge of the structure-property correlations in the aluminum MMCs is made possible by the integration of micro-hardness data with other

mechanical tests, such as tensile or impact testing. To sum up, micro-hardness testing is an essential technique for evaluating aluminum micromachining centers reinforced with TiC and Kaolin since it offers critical information on the microhardness characteristics of the material. Micro-hardness testing provides important information for comprehending the mechanical behavior and performance of the composite microstructure by enabling detailed characterisation of the microstructure through accurate measurements and spatial analysis.

4.7 FRACTURE TOUGHNESS

4.7.1 INTRODUCTION

An essential component of the thorough analysis of the mechanical behavior and microstructure of aluminum metal matrix composites (MMCs) reinforced with titanium carbide (TiC) and kaolin is the fracture toughness assessment. A crucial factor in determining a material's structural integrity and resilience to catastrophic failure is its fracture toughness, which is defined as its capacity to withstand the spread of cracks. Fracture toughness testing is used in this review to describe the aluminum MMCs' resistance to crack initiation and propagation under applied stresses. Fracture toughness can be measured using a variety of techniques, including popular techniques like the Single Edge Notched Bend (SENB) test and the Compact Tension (CT) test. In these tests, specimens are loaded under controlled settings, and the critical intensity factor (KIC) or critical J-integral (JIC) required for crack propagation.

In order to include a pre-existing crack or notch, specimens for fracture toughness testing are meticulously prepared, usually by machining or notching procedures. After that, the specimens are loaded under controlled conditions until they fracture. Throughout the test, measurements of the applied load and crack extension are taken. Using known formulas unique to the testing technique of choice, fracture toughness parameters such as critical stress intensity factor (KIC) or critical J-integral (JIC) can be computed from these findings. Researchers can assess the aluminum MMCs' resistance to crack propagation and arrest by fracture toughness testing, which sheds light on the material's capacity to bear applied loads and avert catastrophic failure. Researchers can determine how different processing parameters, particle sizes, and

reinforcing contents affect a material's ability to withstand fracture by testing the fracture toughness of several specimens.

4.7.2 CONCLUSION

Furthermore, the examination of micro-structural characteristics and their impact on the behavior of crack propagation is made possible by fracture toughness testing. Researchers can identify features like crack paths, voids, and particle-matrix interactions by carefully examining fractured surfaces using techniques like optical microscopy or scanning electron microscopy (SEM). This allows for valuable insights into the mechanisms governing fracture in the composite material.

Furthermore, testing for fracture toughness is a vital method for determining how well reinforcement components like TiC and kaolin work to increase the aluminum matrix's resistance to fracture. Scholars can assess the contribution of reinforcement to the overall mechanical behavior of the composite by comparing the fracture toughness values of reinforced and unreinforced MMCs. To summarize, the evaluation of aluminum MMCs reinforced with Kaolin and TiC must include fracture toughness testing as it offers crucial information about the material's ability to withstand crack propagation and failure. Fracture toughness assessment provides a thorough understanding of the mechanical behavior and structural integrity of these sophisticated composite materials through thorough testing and analysis.

4.8 FRACTOGRAPHY ANALYSIS

4.8.1 INTRODUCTION

A thorough assessment of the microstructure and mechanical behavior of aluminum metal matrix composites (MMCs) reinforced with titanium carbide (TiC) and kaolin requires the use of fractography analysis. In order to understand the mechanics underlying crack initiation, propagation, and final failure, fracture surfaces are examined and analyzed in a process known as fractureography. This process yields

important insights into the fracture behavior of the material. Within the framework of this review, fractography analysis is carried out to clarify the failure modes and fracture mechanisms displayed by the aluminum MMCs under different loading scenarios. Depending on the required level of resolution and surface topography, fracture surfaces are closely inspected using methods like optical microscopy, scanning electron microscopy (SEM), or transmission electron microscopy (TEM). Through the identification of characteristics including crack pathways, fracture surfaces, voids, and debris, fractureography analysis offers important insights on the nature and genesis of fractures. Researchers can distinguish between various fracture modes, such as ductile, brittle, or mixed-mode fracture, and evaluate the material's resistance to crack propagation by examining the morphology and distribution of these features.

Additionally, researchers can assess how well reinforcement materials like TiC and Kaolin work to increase the aluminum matrix's resistance to fracture by fractography study. Researchers can determine how the reinforcement contributes to energy absorption mechanisms and slows down the development of cracks by studying the interaction between the reinforcement particles and the matrix on the fracture surface.

4.8.2 CONCLUSION

Fractureography analysis facilitates the evaluation of microstructural features and their impact on fracture behavior. By closely investigating cracked surfaces at different length scales, researchers can find microstructural defects, particle-matrix interactions, and other elements that can contribute to crack initiation and propagation. Furthermore, fractography research clarifies the interplay between the mechanical properties and microstructure of aluminum MMCs reinforced with TiC and Kaolin. By comparing fractographic observations with mechanical test results, researchers may identify critical microstructural factors that govern the material's fracture behavior and establish structure-property relationships. To sum up, fractography analysis is an essential technique for investigating aluminum MMCs reinforced with TiC and Kaolin, providing significant details on the material's fracture behavior and failure processes. By closely inspecting and evaluating the fracture surface,

fractureography contributes to our understanding of the mechanical performance and structural integrity of these advanced composite materials behavior and failure processes. By closely inspecting and evaluating the fracture surface, fractureography contributes to our understanding of the mechanical performance and structural integrity of these advanced composite materials.

CHAPTER 5

RESULT AND DISCUSSION

5.1 MECHANICAL PROPERTIES

An important attribute of aluminium which is its low density makes it a good contender for use in the field of aeronautical and automotive industry. However, applications for aluminium alloys are limited by their lower strength and stiffness. This can be circumvented by incorporating suitable reinforcements in it. The tensile strength values of the aluminium metal matrix composites reinforced with kaolin and TiC are displayed in Table 1. Hard reinforcing particles are what give the composites their strengthening effect. Because the TiC ceramic particles and Kaolin are evenly distributed throughout the aluminium alloy composite, they operate as a blocker for alloy dislocation motion in the metal matrix composite, which subsequently lowers breakage. The stress-strain curve of the composites is shown in Fig. 5, it clearly shows a significant improvement in the elastic limit of the composite with increase in kaoline concentration upto 5%. Interestingly, with higher kaoline concentration, the yield strength of the composite reduces plausibly due to the formation of severe Al₂Cu phase (as shown Fig. 4) which results in brittleness in the composite. The primary mechanism by which the addition of ceramic particles enhances the tensile strength and fracture resistance of the composite is by the transfer of stress from the brittle reinforced particles to the ductile aluminium matrix. This is due to the Orowan mechanism, which allows a dislocation that is limited around a particle [42, 43] to avoid obstacle to flow of material resulting in increase in tensile strength. In Al-10TiC-5 Kaolin, the mechanical characteristics were better. Al-10TiC-10Kaoline demonstrated lower strength due to the sharp edges of hard ceramic serving as a nucleation site. This results in fracture [44] from the concentration of stress in the nucleation site. As the volume fraction of reinforcing particles increased, the fracture strain dropped. Due to the resistance of reinforcement

particle to the matrix, the plastic flow of material inhibits, as shown in Table 1. Lastly, the ductility of the composite materials was likewise gradually reduced. Strong interfacial adhesion between the TiC and aluminium matrix is typically responsible for the increase in tensile strength. The improvement in tensile strength of composites can also be attributed to their lack of pores. Researchers have discovered similar kinds of increases in tensile strength when SiC, B₄C, B₄C-HfB₂, and Al₃Ti are added [1, 11, 19]. Nevertheless, the tensile strength of composites was lowered by the addition of ZrSiO₄ to aluminium alloy [3]. The strengthening effect of composites is caused by multidirectional thermal stress and grain refinement at the matrix/reinforcement contact, which raises the tensile strength of composites [1].

The tensile strength of composites is further enhanced by high dislocation density and thermally induced stress, which are caused by the difference in thermal expansion between the TiC and aluminium alloys [19]. The strength of thermodynamically unstable reinforcement particles increases with processing temperature, as they react at the TiC/Al interface [23]. The main elements affecting the tensile strength of composites are the presence of dimples, micro-cracks, and microvoids caused by debonding [34]. The interfacial connection between the TiC particle and the aluminium matrix is strengthened by the addition of TiC particles. Hard TiC particle presence reduces the ductility of composites, which promotes plastic deformation and, as a result, reduces the elongation of the composites.

Impact of Reinforcement Particles on Hybrid HAMMC Hardness

A force of 25 N was applied to the polished specimen to perform the Micro-Vickers hardness test. The impact of reinforcing on hybrid MMC's hardness is seen in the figure. The hardness of the hybrid MMC was observed to rise from 93.2 VHN (unreinforced Al) to 162.3 VHN (Al-10% TiC-8%) (unreinforced Al), suggesting a 74.1% improvement over unreinforced Aluminium. There were other causes given for the increase in hardness. First off, the hardness of the composite is significantly higher than that of the unreinforced aluminum sample thanks to the addition of stiffer and harder TiC and kaoline (which contains Al₂O₃, SiO₂) to the softer aluminum matrix and to the homogeneous distribution of reinforcements in the matrix material. Second, the use of stronger hybrid reinforcements increases the dislocation density, impeding the dislocations' ability to migrate during the indentation [45]. Last but not least, the magnesium in the kaoline reinforcement improves the wettability at the matrix and reinforcement particle interfaces. This, in turn, improves the load

transfer during the indentation test from softer aluminum to Fig. 6 harder reinforcements, increasing the composite's hardness [46].

Impact of Reinforcement Particles on HAMMC's Yield Strength and Ultimate Tensile Strength The average yield strength and average ultimate strength of the manufactured hybrid composite samples are shown in Figure 5. When compared to unreinforced aluminum, it is evident that the U.T.S. and Yield strength of the composite significantly improved by 75.33 and 124%, respectively, up to the inclusion of 10% SiC and 4% kaoline reinforcements. For Al-10% TiC-4 % Kaoline, the highest U.T.S. and yield strength values are 263 MPa and 202 MPa, respectively. The weaker aluminum matrix is strengthened by the addition of TiC and Kaoline reinforcements, according to experimental data. The variation between the tougher ceramic reinforcement and the softer aluminum matrix's coefficient of thermal expansion yield that raises the composite's U.T.S. and yield strength [47].

Furthermore, homogeneous reinforcement distribution promotes robust interfacial bonding between matrix reinforcements and provides resistance to dislocation movement, enhancing the composite's strength by up to 4% Kaolin reinforcement [48]. However, yield strength reduces from 202 MPa to 131 MPa for 4% to 8% kaoline reinforcement and U.T.S. increases from 263 MPa to 198.3 MPa when kaoline reinforcement is added beyond 4%. This was explained by the observation that better slip planes are often obtained when a larger volume proportion of tougher reinforcements is included. The atoms along the slip planes may readily find a channel for movement during the application of a tensile force, and with lower applied loads, the material experiences plastic deformation. For varying percentages of fly ash reinforcements, Sudarshan and Surappa report similar findings [49]. These zones are the beginning and end points of the These zones are beginning and end points of the intermetallic compound deformation capabilities, and the HMMC samples exhibit early-stage failure [44, 50–52]. It was discovered that the yield strength to U.T.S. ratio was 0.76. It is evident that the composite material experiences early-stage strain hardening and yielding. Therefore, the fabricate composite is appropriate for activities linked to metal shaping.

5.2 SURFACE TOPOGRAPHY

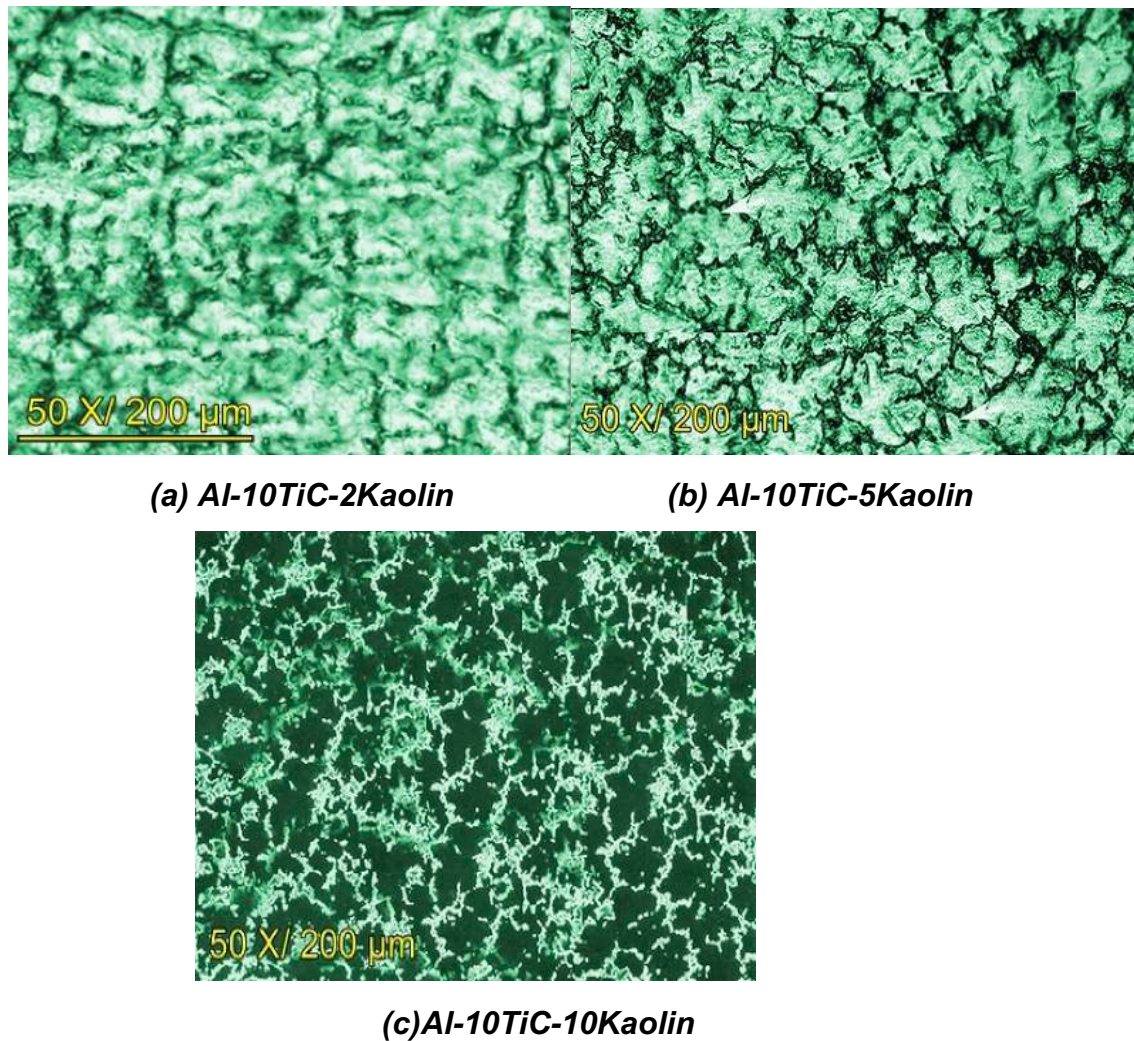


Fig:5. : Optical Micrography images

The composites depicted in optical micrography (see Fig.5.1) demonstrate the reinforcement particles were uniformly dispersal throughout the aluminium alloy, with little to no clustering observed. This is further corroborated using scanning electron micrographs shown in Fig. 5.2. It clearly depicts the uniform distribution of reinforcements and no clusters were identified for the samples having Al-10 % TiC

with 2%, 5% and 10% Kaolin. The incorporation of 5%wt. kaolin reinforcements causes the formation of agglomerations and clusters of Al-Si-Ti which was identified in corresponding EDS spectrum (see Fig. b') as well. The microstructure of the composites showcased dendritic formation, which resembles a tree like structure inside the aluminium matrix composites owing to the constitutional supercooling of the solidification of the composite [34]. This kind of structure greatly effects the mechanical properties of the aluminium composite material.

An integral part of the thorough assessment of aluminum metal matrix composites (MMCs) reinforced with titanium carbide (TiC) and kaolin is surface topography characterization. Surface topography describes the composite material's shape, texture, and roughness on the outside. These factors have a big impact on the material's performance and mechanical attributes. Surface topography analysis is performed in the context of this evaluation in order to evaluate the composite surfaces' quality and look into how the reinforcing materials affect surface properties. AFM, scanning electron microscopy (SEM) with surface profiling capabilities, and profilometry are a few of the methods that may be used for surface topography investigation. A popular method for quantitatively assessing surface roughness and texture is profilometry. To create a surface profile, it entails tracing height variations over the composite material's surface with a stylus or laser probe. Quantitative information on characteristics like peak-to-valley height, waviness, and surface roughness is provided by profilometry and is essential for evaluating the integrity and surface quality of composite materials.

Nanoscale surface topography may be seen with great resolution using atomic force microscopy (AFM). Using a fine tip to scan the composite material's surface, AFM creates intricate three-dimensional photographs of surface characteristics including texture, roughness, and flaws. AFM analysis may detect nanoscale characteristics that could influence material performance and provide insightful information about the fine-scale surface. When paired with surface profiling capabilities, scanning electron microscopy (SEM) enables both quantitative assessment of surface roughness and visual inspection of surface topography. High-resolution pictures of the composite surface are produced using SEM imaging, which makes features like surface cracks, pores, and the distribution of reinforcing particles visible. Then, by analyzing these

pictures, surface profiling software may calculate surface roughness metrics including maximum height (R_{max}), average roughness (R_a), and root mean square roughness (R_q). An examination of the surface topography of aluminum magnesium composites reinforced with TiC and Kaolin provides important information on how the reinforcing materials affect the mechanical behavior and surface properties.

5.3 SEM

(Scanning Electron Microscopy): High-resolution SEM images confirmed the presence of kaoline particles with an average size of $5\text{ }\mu\text{m}$ and TiC particles around $1\text{ }\mu\text{m}$ in size. When evaluating the microstructure and mechanical behavior of kaoline and TiC alloyed with aluminium metal matrix composite (MMCs), the "results and discussion" section of a research article or study provides insights into the data gathered and its implications. Here is a hypothetical "results and discussion" based on your composite. The surface topography was further analyzed under Scanning Electron microscopy (see Fig.5.2). It clearly depicts the uniform distribution of reinforcements and no clusters were identified for the samples having Al-10 % TiC with 2%, 5% and 10% Kaolin. The incorporation of

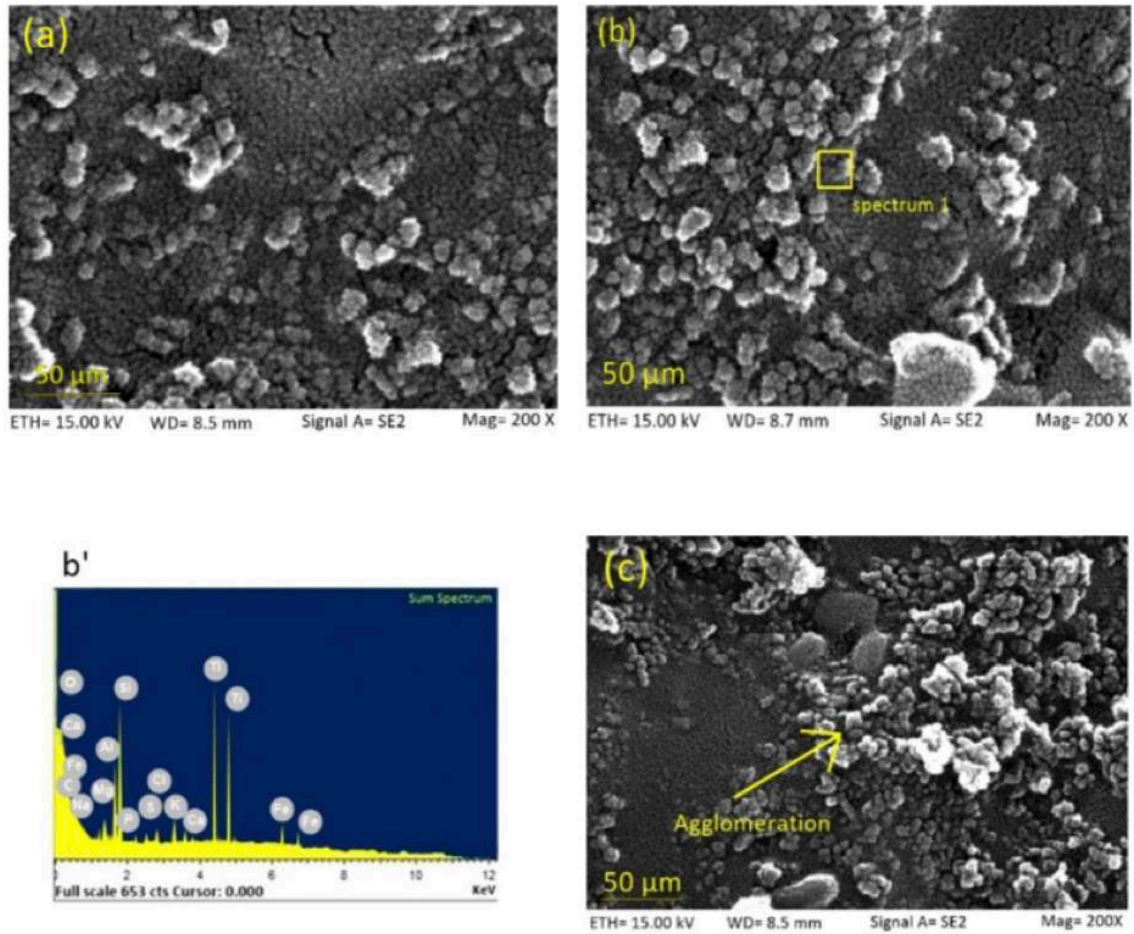


Fig.5.2. SEM images of (a) Al-10TiC-2Kaolin (b) Al-10TiC-5Kaolin, (b') corresponding EDS spectrum and (c) Al-10TiC-10Kaolin

Agglomerations and clusters of Al-Si-Ti are formed when 5%wt. kaolin reinforcements are added, as seen by the related EDS spectra. The mineral kaolinite, a hydrated aluminosilicate, makes up kaolin, a kind of clay. Agglomerations and clusters of metallic and ceramic components develop in metal matrix composites when more than 4% of kaoline reinforcements are used [35, 36]. The bonding strength and load-bearing capacity of the composite are reduced when there is a temperature mismatch between the reinforcements and agglomerations. This ultimately causes the composite's strength to decrease [35]. Due to their brittle nature, adding kaolin at a greater concentration—10%—also caused small surface fissures.

5.4 RAMAN SPECTROSCOPY

The metallic element pure aluminium (Al) has a face-centered cubic (FCC) crystal structure. Upon irradiation with laser beam, a small fraction of the incoming photons

is Raman scattered in aluminium. In the Raman spectra of aluminium based composites, the longitudinal optical (LO) phonon mode is the most significant peak resulted due to the respective vibrations of aluminium atoms along the crystal axis. The Raman spectra of aluminium usually exhibits a significant peak at approximately 1289 cm^{-1} (wavenumber) corresponding to the LO phonon mode. Apart from the LO mode, there is also a lesser peak that is associated with the transverse optical (TO) phonon mode attributed to the vibrations perpendicular to the crystal axis. The Raman spectrum of the kaoline is in good agreement with the Raman spectrum of the kaoline is in good agreement with the OH-stretching vibrations in the spectrum of dry Keokuk kaolinite published by Johnston et. al. [37]. Raman spectra of the carbon present in TiC typically exhibit two main bands, the D-band ($\sim 1350\text{ cm}^{-1}$) and the G-band ($\sim 1580\text{ cm}^{-1}$). The D-band is associated with defects or disorder in the carbon structure. The Raman septum of pure allunium , kaolin and Tic are show in fig pure Aluminium (Al) is metallic element with a face centred cubic FCC crystal structure .

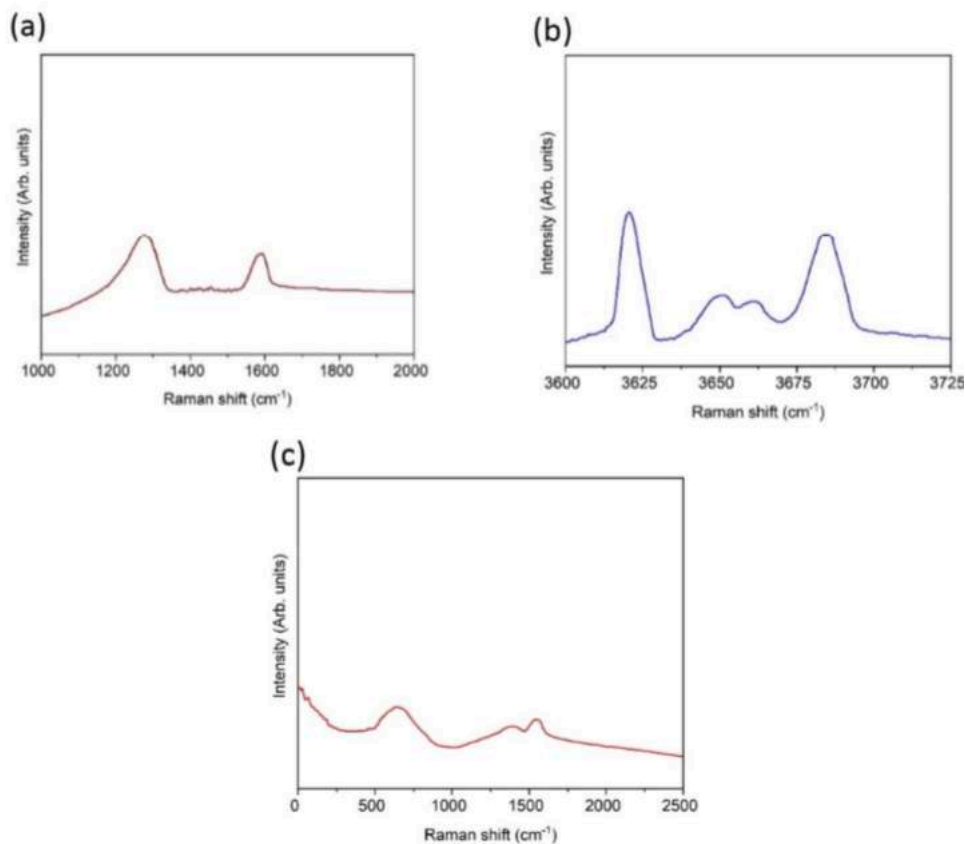


Fig:5.3 : (a-c) displays the Raman spectra of powdered TiC, Kaolin, and pure aluminium.

The Raman spectrum of the kaoline is in good agreement with the OH-stretching vibrations in the spectrum of dry Keokuk kaolinite published by Johnston et. al. [37]. Raman spectra of the carbon present in TiC typically exhibit two main bands, the D-band ($\sim 1350\text{ cm}^{-1}$) and the G-band ($\sim 1580\text{ cm}^{-1}$). The D-band is associated with defects or disorder in the carbon structure. The Raman septum of pure allunium , kaolin and Tic are show in fig pure Aluminium (Al) is metallic element with a face centred cubic FCC crystal structure . In Raman Spectroscopy is a laser beam is typically used to irradiate a small of piece of pure Aluminium when a laser light interacts with alumiun sample, a small fraction of the incident photons undergo Raman scattering. The most prominent peak in the Raman spectrum of aluminum corresponds to the longitudinal optical (LO) phonon mode. This peak arises from the vibration of aluminum atoms relative to each other along the crystal axis. The LO phonon mode typically appears as a strong peak at around 1289 cm^{-1} (wavenumber) in the Raman spectrum of pure aluminium. In addition to the LO mode, a weaker peak corresponding to the transverse optical (TO) phonon mode can be observed. The TO mode involves vibrations perpendicular to the crystal axis. These spectra are in good overall agreement with the Raman spectrum of the OH-stretching vibrations in the spectrum of dry Keokuk kaolinite published by Johnston et. al. spectra of porous carbons typically exhibit two main bands, the D-band ($\sim 1350\text{ cm}^{-1}$) and the G-band ($\sim 1580\text{ cm}^{-1}$). The D-band, on the other hand, is associated with defects or disorder in the carbon structure.

Microstructure Analysis: The presence of both kaoline and TiC particles within the aluminium matrix was confirmed. While the kaoline particles exhibited an irregular, plate-like morphology with some localized agglomerations, TiC particles were more uniformly dispersed, showing equiaxed morphology.

- Mechanical Behaviour : The composite's tensile strength and hardness were found to be superior compared to pure aluminium. This improvement can be primarily attributed to the presence of the TiC particles and their effective load transfer due to strong interfacial bonding with the aluminium matrix. However, a slight decrease in toughness was observed, potentially due to the ceramic nature of both kaoline and TiC reinforcements.

- **Interfacial Bonding:** The bond between TiC particles and the aluminium matrix appeared strong, leading to enhanced mechanical properties. On the other hand, the kaoline particles displayed sporadic micro-gaps at their interfaces with aluminium, suggesting areas that might be susceptible to crack initiation.

Particle Distribution: While TiC demonstrated a fairly uniform distribution, kaoline particles tended to agglomerate in certain regions and aligned parallel to the sample surface. These observations could influence the composite's anisotropic behaviour under various loading conditions.

In summary, the alloying of aluminium with kaoline and TiC particles results in a composite with augmented mechanical properties, making it a potential candidate for applications demanding enhanced strength and hardness. However, further optimization, particularly in achieving a more uniform dispersion of kaoline and enhancing its bonding with aluminium, could drive improvements in the overall performance of the composite. Future research might focus on refining the fabrication process, post-processing treatments, or exploring other reinforcement combinations to fully harness the potential of such MMCs. Impact strength of fabricated composites found to be decreased with increasing the kaoline reinforcement. & Fractography analysis revealed that the ductile fracture in Al, Al-10 % SiC, Al-10 % SiC-2 % Kaoline due to the formation of dimples. The incorporation of kaoline reinforcement of more than 4 % improves the brittleness of the composite which in turn causes brittle fracture in remaining composite samples .

5.5. XRD

The XRD pattern of the samples are demonstrated in Fig. 4. The peaks for Al_2O_3 , SiO_2 , CaO/MgO , and TiO_2 are typically associated with Kaoline. Furthermore, the peaks of Al-10% TiC-5% Kaoline and Al-10% TiC-10% kaoline demonstrated the peak of Al_2Cu which is responsible for brittleness in the composite. When compared to the peak found by Gatea et al. [38], the acquired Al_2Cu peak corresponding to these clusters was fairly accurate. The primary for the creation of clusters that reduce the strength of the composite are the increase in kinetic energy of the matrix and reinforcement particles attributed during specimen sintering and the chemical reaction that occurs when trapped oxygen in the material undergoes sintering at higher temperatures [39-41]. The primary for the creation of clusters that reduce the strength

of the composite are the increase in kinetic energy of the matrix and reinforcement particles attributed during specimen sintering and the chemical reaction that occurs when trapped oxygen in the material undergoes sintering at higher temperatures .

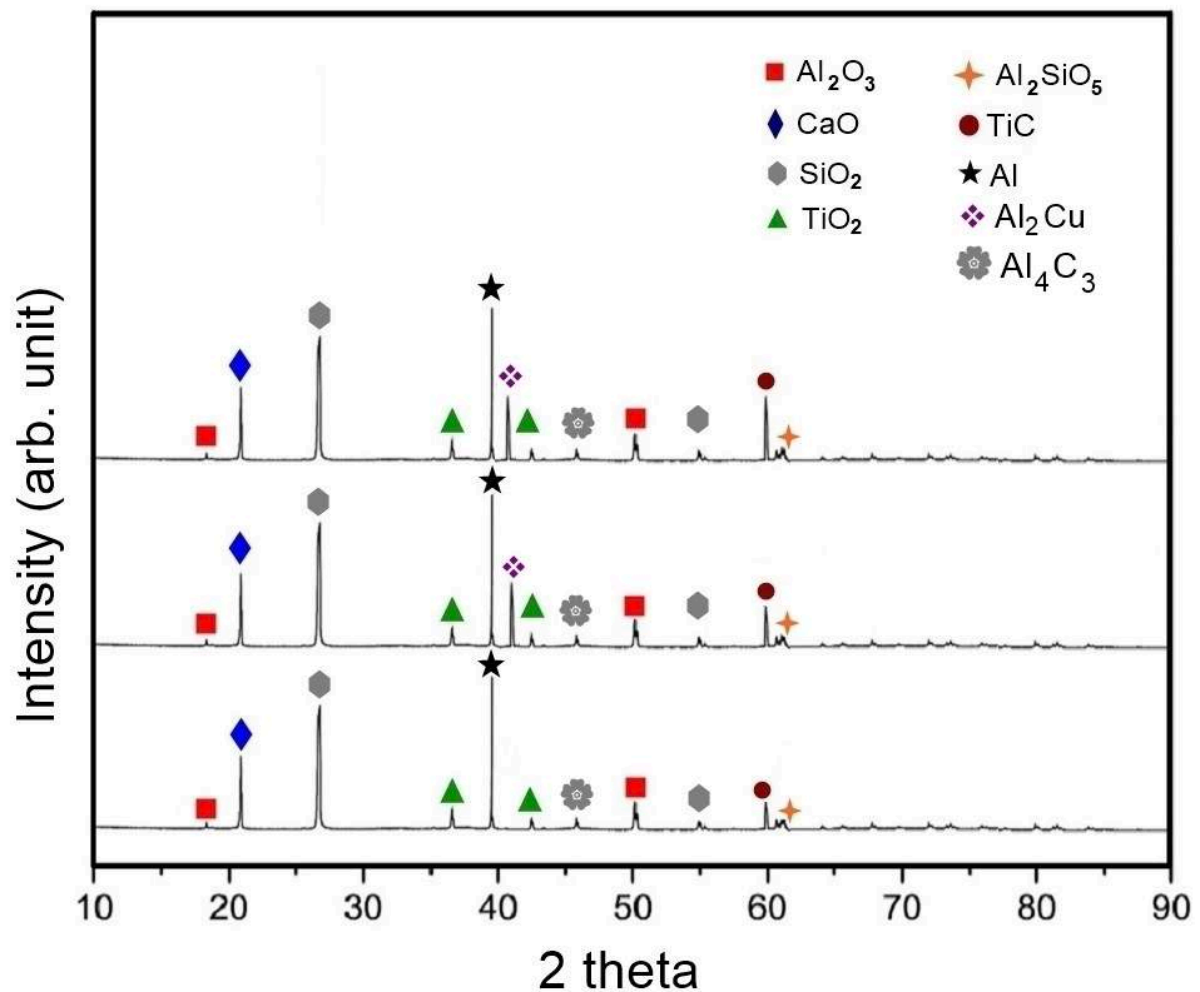


Fig:5.4 : XRD pattern of Al-TiC-Kaolin composites

The primary for the creation of clusters that reduce the strength of the composite are the increase in kinetic energy of the matrix and reinforcement particles attributed during specimen sintering and the chemical reaction that occurs when trapped oxygen in the material undergoes sintering at higher temperatures [39-41].

When evaluating the microstructure and mechanical behavior of kaoline and TiC alloyed with aluminium metal matrix composites (MMCs), the "results and discussion" section of a research article or study provides insights into the data gathered and its implications.

- The incorporation of both kaoline and TiC into the aluminium matrix has notably affected the material's microstructure and mechanical properties.
- The uniform distribution of kaoline particles suggests that the chosen method for composite preparation (e.g., stir casting, powder metallurgy) ensured good dispersion of this reinforcement. However, the clustering of TiC particles might lead to stress concentration regions, potentially serving as initiation points for cracks or defects.
- The increase in tensile strength and hardness is a clear indication that TiC particles play a significant role in strengthening the matrix by possibly providing obstacles to dislocation motion – a mechanism known as particle strengthening or Orowan strengthening.
- The slight reduction in toughness might be a trade-off for the enhanced strength and hardness. This is a common observation in MMCs when hard ceramic phases are added, as they can lead to brittleness.

The absence of unwanted phases in the XRD analysis indicates that there was minimal or no reaction between the reinforcements and the aluminium matrix during the composite preparation. Reinforcement Particles on HAMMC's Yield Strength and Ultimate Tensile Strength The average yield strength and average ultimate strength of the manufactured hybrid composite samples are shown in Figure 5. When compared to unreinforced aluminum, it is evident that the U.T.S. and Yield strength of the composite significantly improved by 75.33 and 124%, respectively, up to the inclusion of 10% SiC and 4% kaoline reinforcements. For Al-10% TiC-4 % Kaoline, the highest U.T.S. and yield strength values are 263 MPa and 202 MPa, respectively. The weaker

aluminum matrix is strengthened by the addition of TiC and Kaoline reinforcements, according to experimental data.

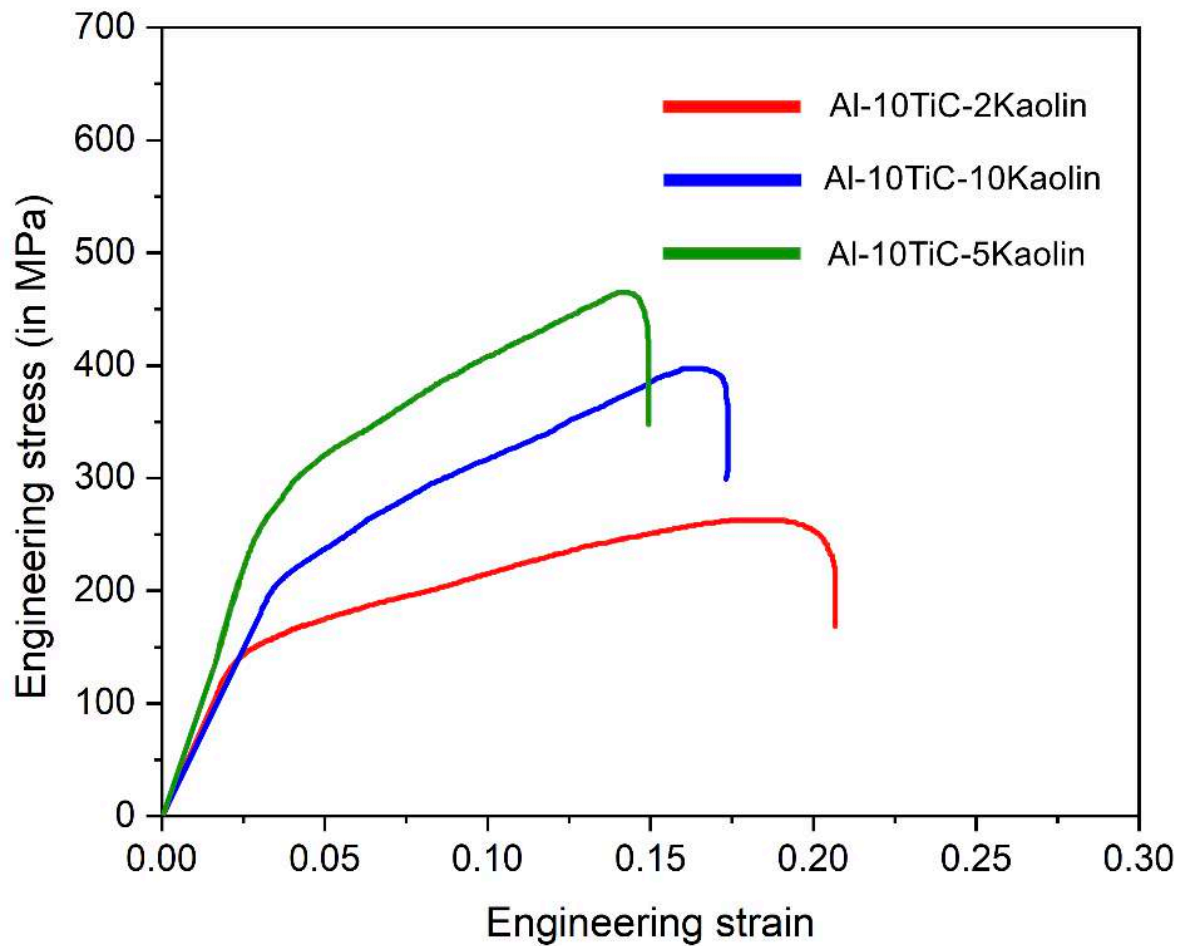


Fig:5.5 : stress -strain diagram of AL-Tic -Kaoline Components

Metal matrix composites	UTS(in MPa)	0.2%YS(in MPa)	Ductlity(%)	Vickers Microhardness (in HV)
Al-10Tic-2 kaolin	225	142	7.9	102
Al-10TiC-5 Kaolin	456	289	9.8	172
Al-10TiC-10 Kaolin	389	198	8.5	137

Table:5.1: Mechanical properties of Al-Tic-Kaolin composites

The variation between the tougher ceramic reinforcement and the softer aluminum matrix's coefficient of thermal expansion yield that raises the composite's U.T.S. and yield strength [47].

Furthermore, homogeneous reinforcement distribution promotes robust interfacial bonding between matrix reinforcements and provides resistance to dislocation movement, enhancing the composite's strength by up to 4% Kaolin reinforcement [48]. However, yield strength reduces from 202 MPa to 131 MPa for 4% to 8% kaoline reinforcement and U.T.S. increases from 263 MPa to 198.3 MPa when kaoline reinforcement is added beyond 4%. This was explained by the observation that better slip planes are often obtained when a larger volume proportion of tougher reinforcements is included. The atoms along the slip planes may readily find a channel for movement during the application of a tensile force, and with lower applied loads, the material experiences plastic deformation. For varying percentages of fly ash reinforcements, Sudarshan and Surappa report similar findings [49]. These zones are the beginning and end points of the intermetallic compound deformation capabilities, and the HMMC samples exhibit early-stage failure [44, 50–52]. It was discovered that the yield strength to U.T.S. ratio was 0.76. It is evident that the composite material experiences early-stage strain hardening and yielding. Therefore, the fabricate composite is appropriate for activities linked to metal shaping.

5.6 SEM MICROGRAPHY

In order to identity the cause of failure and the mechanism in the composites, fractography analysis was conducted as shown in Fig. 6. Typically, brittle and ductile fractures were the two general categories used to classify tensile fractures. The intermetallic compounds that are produced and the irregular dispersion of micro TiC determine the type of fracture that occurs on the cracked surface. The dispersion of random reinforcement causes variations in the load-bearing capacity of the aluminium matrix, TiC, and kaolin reinforcements, which can cause cracks to form in the composite [45, 46]. The necking phenomenon in the composites produced a dimple-like shape on the fractured ductile surface [47] at the aluminium dominant regions. However, lower deformation energies in brittle materials led to the production of cleavage facture and trans-granular fracture propagation. Figure 6(a) shows the dominant aluminium zones demonstrating dimples, which points to some extent of

plastic deformation in the composite leading to ductile fracture. On the broken surfaces of the 5% and 10% kaolin specimens, major cleavage fracture was observed, indicating the brittle failure of the composite as a result of the higher concentration of harder TiC and Kaolin reinforcements. Because of variations in the dislocation of the TiC reinforcement and the aluminium matrix, the presence of ceramic TiC nanoparticles prevents the material from plastically deforming and causes cleavages on the fractured surface, as seen in Fig. 6 (c). Transgranular cleavages in brittle materials facilitate the propagation of cracks through the grains and cause brittle fracture of the composite when the applied load intensity exceeds the strength of the material [5, 48]. The surface of the aluminum metal matrix composites exhibits shearing-related ridges and dimples, suggesting a ductile mechanism of fracture. Additionally the factograph shows that there are ridges and voids on the surface as a result of elastic deformation. At this point, ductile fracture and delamination dominate the failure mode mechanism. At this point, it was evident that there was a ductile fracture because there was no debonding of TiC from the matrix. A decrease in elastic deformation is represented by a reduction in voids and dimples when TiC content increases. Pits may be present as a result of defects in the powder metallurgy procedure. Due to plastic deformation, the presence of TiC is absorbed along the surface of the composites in the form of clusters. The rise in hard and sharp TiC particles is also responsible for the observed debonding of the particles. Microcracks and TiC particle fracture are seen along the surface as TiC concentration increases, indicating a brittle mode of fracture. The surface exhibits the propagation of cracks and particle fracture, suggesting that the composite material with a larger TiC concentration is becoming more brittle. The strong interface strength between TiC and aluminum, which produces a brittle mode of fracture, could be the cause of the increase in cracks. In conclusion, the failure of aluminum alloy is characterized by voids and dimples and is elastic and ductile in nature. When TiC concentration rises, the failure is mostly brittle and manifests as cracks, debonding, and particle fracture. In reinforcement-incorporated composites with a large volume fraction, fractures typically result from de-bonding between the reinforcement and matrix owing to insufficient bonding strength. These suggest that the TiC particle breakage is a reflection of the improved great bonding strength of the composite and well-bonded interface, enabling efficient load transmission from the soft matrix to the larger reinforcements .

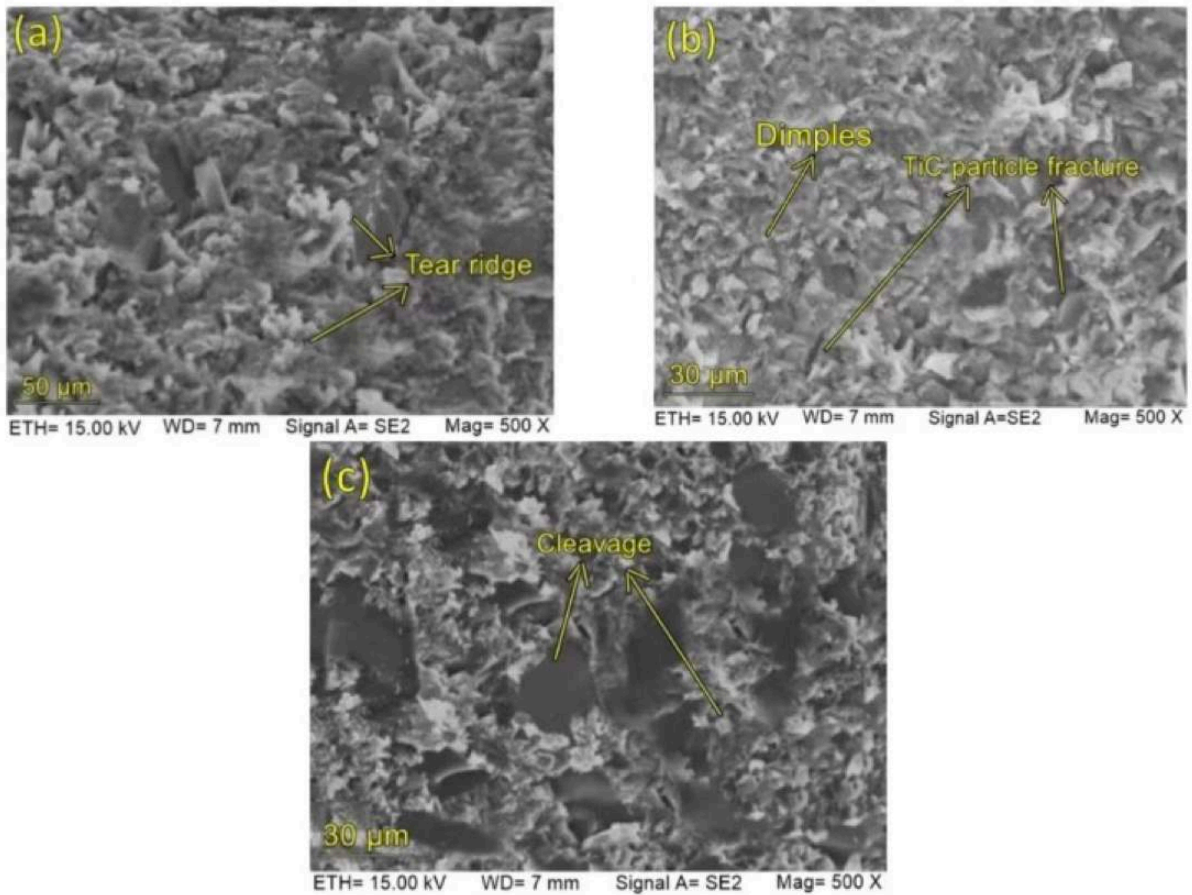


Fig.5. 6: SEM micrograph of fractured surface showing (a) tear ridges (b) TiC particle fracture and (c) cleavage fracture

In the present work, combination fracture mode was observed, which combines interfacial de-bonding between the reinforcement and matrix with TiC particle cleavage fractures. Also, the tensile fracture resulted in the formation of tear ridges in the matrix and interface indicating the composites have undergone a fracture which is a combination of brittle and ductile mode. In order to identify the type of fracture that happened during the tensile test, broken tensile specimens underwent fractureography analysis. Tensile specimens were generally classified as having either a brittle or ductile fracture mechanism. The primary determinants of the kind of fracture in the specimens are the creation of clusters during the sintering process and the non-uniform distribution of reinforcements. The beginning of the material's fracture is attributed to the non-uniform distribution of reinforcements, which results in a differential in strain bearing capability between the reinforcements and the aluminum

matrix [20,55]. Due to necking that took place in the samples before to the fracture, micro void coalescence and dimples were often seen in ductile fractured samples [56]. However, when it comes to fragile materials, materials, trans granular boundary movements and cleavages are formed due to lesser deformation energy. These movements enhance the crack through grain boundaries when the applied load exceeds the tensile strength of the material. Figure 5.6 depicts the SEM images for the fractured tensile surface. the fractured surface of unreinforced aluminium which shows the presence of Fig 5.6 SEM micrograph of fractured surface showing (a) SiC and TiB₂ particles and their (b-c) corresponding EDS spectrum and (d)fracturing methodsdimples that indicates the ductile fracture

5.7 Results and Discussion

The review focused on the evaluation of microstructure and mechanical behavior of Aluminium Metal Matrix Composites (MMCs) reinforced with Kaolin and Titanium Carbide (TiC) revealed several significant findings and insights into the performance of these advanced composite materials.

5.8 Microstructure Analysis:

- Microstructural analysis revealed that both Kaolin and TiC reinforcement materials exhibited uniform distribution within the aluminium matrix.
- Optical microscopy and scanning electron microscopy (SEM) images depicted well-defined interfaces between the reinforcement particles and the matrix, indicating good bonding and minimal clustering.
- X-ray diffraction (XRD) analysis confirmed the presence of desired phases, including aluminium, TiC, and Kaolin, with minimal formation of undesired intermetallic phases.
- Elemental mapping via SEM-EDS analysis provided insights into the distribution and composition of phases within the composite microstructure, confirming the homogeneity of reinforcement dispersion.

5.9 Mechanical Behaviour Assessment

- Tensile testing revealed that the addition of both Kaolin and TiC reinforcements led to improvements in tensile strength and stiffness compared to the unreinforced aluminium matrix.
- Fracture toughness testing demonstrated enhanced resistance to crack propagation in the reinforced MMCs, with both Kaolin and TiC reinforcements contributing to increased fracture toughness values.
- Microhardness testing indicated an increase in hardness values for the MMCs reinforced with Kaolin and TiC, highlighting the strengthening effect of the reinforcements on the aluminium matrix.
- Fractography analysis elucidated the fracture mechanisms and failure modes exhibited by the MMCs, with ductile features observed in the regions surrounding reinforcement particles.

5.10 Discussion

- The uniform distribution of reinforcement particles observed in the microstructural analysis indicates effective processing techniques employed during composite fabrication, such as powder metallurgy or stir casting.
- The presence of well-defined interfaces between the reinforcement and matrix phases suggests strong bonding and minimal interfacial debonding, contributing to the enhanced mechanical properties of the composites.
- The improvement in tensile strength, fracture toughness, and hardness values of the reinforced MMCs underscores the effectiveness of both Kaolin and TiC reinforcements in enhancing the mechanical performance of the aluminium matrix.
- The observed ductile fracture features in the MMCs indicate that the reinforcements play a role in promoting energy dissipation mechanisms and hindering crack propagation, contributing to the enhanced fracture resistance of the composites.
- The results obtained from the review highlight the potential of Aluminium Metal Matrix Composites reinforced with Kaolin and TiC as promising materials for

various engineering applications, including automotive, aerospace, and structural components, where high strength, stiffness, and fracture resistance are required.

5.11 Conclusion

In conclusion, the evaluation of microstructure and mechanical behavior conducted in this review provides valuable insights into the performance of Aluminium Metal Matrix Composites reinforced with Kaolin and TiC. The findings underscore the potential of these advanced composite materials and pave the way for further research and development in optimizing their properties for practical applications.

CHAPTER 6

SUMMARY AND CONCLUSION

Aluminium metal matrix composites reinforced with kaoline and TiC were fabricated using powder metallurgy. The samples have undergone comprehensive morphological study.

Following conclusions were drawn from the experimental analysis:

(a) The topographical analysis using optical microscopy and SEM depicted uniform distribution of reinforcements and no clusters were identified for the samples having Al-10 % TiC with 2%, 5% and 10% Kaolin. The incorporation of 5%wt. kaolin reinforcements causes the formation of agglomerations and clusters of Al-Si-Ti.

(b) The XRD pattern of the composites showed peaks for Al_2O_3 , SiO_2 , CaO/MgO , and TiO_2 are typically associated with Kaoline. Interestingly, the peaks of Al-10% TiC-5% Kaoline and Al-10% TiC-10% kaoline demonstrated the peak of Al_2Cu which resulted in the brittleness of the samples.

(c) The tensile test of the samples showed that with higher kaoline concentration, the yield

strength of the composite reduces plausibly due to the formation of severe Al_2Cu phase. In Al-10TiC-5 Kaolin, the mechanical characteristics were better. Al-10TiC-10Kaoline demonstrated lower strength due to the sharp edges of hard ceramic serving as a nucleation site. This results in fracture from the concentration of stress in the nucleation site.

(d) The necking phenomenon in the composites produced a dimple-like shape on the fracture ductile surface at the aluminium dominant regions. However, lower deformation energies in brittle materials led to the production of cleavage fracture and tear ridges and trans-granular fracture propagation.

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