

**MORPHOLOGICAL STUDY OF SiC AND TiB<sub>2</sub> REINFORCED  
ALUMINIUM METAL MATRIX COMPOSITE**

**A Project Report Phase – II**

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

by

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

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**APRIL– 2023**



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**BONAFIDE CERTIFICATE**

This is to certify that the Project Report is the Bonafide work of **MADHAVI LATA VANGARA (39260042)** and **REHMATH BAZIL (39260025)** who carried out the project entitled "**MORPHOLOGICAL STUDY OF SiC AND TiB<sub>2</sub> REINFORCED ALUMINIUM METAL MATRIX COMPOSITE**" under my supervision from November 2022 to April 2023.

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**Submitted for Viva voce Examination held on -----**

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## DECLARATION

We, **MADHAVI LATA VANGARA (39260042)** and **REHMATH BAZIL (39260025)** hereby declare that the Project Report entitled "**MORPHOLOGICAL STUDY OF SIC AND TIB<sub>2</sub> REINFORCED ALUMINIUM METAL MATRIX COMPOSITE**" done by us under the guidance of **Dr. LOKESHWAR PATNAIK, M.E., Ph.D.**, Department of Aeronautical Engineering, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

**DATE:** 25.04.2023

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## ABSTRACT

In this study, the effect of  $\text{TiB}_2$  particles on the microstructural and mechanical behaviour of Al-SiC- $\text{TiB}_2$  Hybrid metal matrix composite was investigated. Al - 10% SiC- X%  $\text{TiB}_2$  composite samples were fabricated through powder metallurgy technique or stir casting by applying a compaction pressure. The surface topography and structure of the material is obtained using OM, AFM, SEM-EDS and XRD analysis. Further, the fabricated composite samples were subjected to density, hardness, tensile and impact tests to study the mechanical behaviour of fabricated hybrid composite using Archimedes principal, microhardness test, scratch test, tensile test and Impact test respectively. Compared to steel and nickel-based materials, aluminium matrix composites (AMCs) offer excellent specific strength and stiffness. When compared to monolithic superalloys, high-temperature AMCs can save weight by up to 50% while keeping the same stiffness and strength in the propulsion systems of jet engines. Whether continuous fibres or discontinuous particles are used as reinforcement, the special qualities of AMCs have propelled them to the forefront of major research and development projects across the globe. AMCs are among the most researched and sought-after material systems, yet there is a lack of meaningful information regarding their properties, manufacturing processes, and design in the literature. This report discusses significant studies that helped enhance AMCs material systems. Additionally, it offers thorough information on typical reinforcements, production procedures, and reviews.

## TABLE OF CONTENTS

| CHAPTER<br>NO. | TITLE                                   | PAGE<br>NO. |
|----------------|-----------------------------------------|-------------|
|                | ABSTRACT                                | v           |
|                | LIST OF FIGURES                         | ix          |
|                | LIST OF TABLES                          | x           |
| 1              | INTRODUCTION                            | 1           |
|                | 1.1 INTRODUCTION TO COMPOSITE MATERIAL  | 1           |
|                | 1.1.1 ADVANTAGES OF COMPOSITE MATERIALS | 1           |
|                | 1.2 REINFORCEMENT                       | 2           |
|                | 1.3 PROPERTIES OF VARIOUS REINFORCEMENT | 3           |
|                | 1.4 COMPOSITE MANUFACTURING TECHNIQUES  | 4           |
|                | 1.4.1 FRICTION STIR PROCESSING          | 4           |
|                | 1.4.2 POWDERMETALLURGY                  | 5           |
|                | 1.4.3 INFILTRATION METHOD               | 6           |
|                | 1.4.4 CASTING METHOD                    | 6           |
|                | 1.5 COMPOSITE APPLICATIONS              | 7           |
|                | 1.5.1 AEROSPACE                         | 7           |
|                | 1.5.2 SPORTS AND RECREATION             | 8           |
|                | 1.5.3 MARINE                            | 8           |
| 2              | LITERATURE SURVEY                       | 9           |
| 3              | AIM AND SCOPE                           | 12          |
|                | 3.1 AIM AND SCOPE OF PRESENT WORK       | 12          |
| 4              | MATERIAS AND METHODOLOGY                | 13          |
|                | 4.1 MATERIALS USED                      | 13          |
|                | 4.1.1 ALUMINIUM POWDER                  | 12          |
|                | 4.1.2 ATOMIC DATA OF ALUMINIUM          | 14          |
|                | 4.1.3 PHYSICAL PROPERTIES OF ALUMINIUM  | 14          |
|                | 4.1.4 MECHANICAL PROPERTIES             | 15          |
|                | 4.1.5 ADVANTAGES OF ALUMINIUM           | 16          |
|                | 4.2 SILICON CARBIDE POWDER              | 18          |
|                | 4.2.1 SILICON CARBIDE AS REINFORCEMENT  | 18          |

|          |                                                          |           |
|----------|----------------------------------------------------------|-----------|
|          | <b>4.3 TITANIUM DI-BORIDE</b>                            | <b>19</b> |
|          | <b>4.3.1 MATERIAL DISCRIPTION</b>                        | <b>19</b> |
|          | <b>4.3.2 POTENTIAL TITANIUM BI-BORIDE APPLICATION</b>    | <b>19</b> |
|          | <b>4.4 METHODOLODY</b>                                   | <b>20</b> |
|          | <b>4.4.1 METHODOLOGY FLOW CHART</b>                      | <b>20</b> |
|          | <b>4.4.2 OBJECTIVES</b>                                  | <b>21</b> |
|          | <b>4.4.3 POWDER METALLURGY</b>                           | <b>21</b> |
|          | <b>4.4.4 BENEFITS OF POWDER METALLURGY PROCESS</b>       | <b>22</b> |
|          | <b>4.5 TESTING</b>                                       | <b>24</b> |
|          | <b>4.5.1 DESTRUCTIVE AND NON-DESTRUCTIVE TEST</b>        | <b>24</b> |
|          | <b>4.5.1.1 DESTRUCTIVE TESTING</b>                       | <b>24</b> |
|          | <b>4.5.1.2 THE NEED THE DESTRUCTIVE TESTING</b>          | <b>24</b> |
|          | <b>4.5.1.3 DESTRUCTIVE TESTING BENEFITS</b>              | <b>25</b> |
|          | <b>4.5.2 NON-DESTRUCTIVE TESTING</b>                     | <b>25</b> |
|          | <b>4.5.2.1 DEFINITION OF NON-DESTRUCTIVE TESTING</b>     | <b>25</b> |
|          | <b>4.5.2.2 SAVING WITH NDT</b>                           | <b>26</b> |
|          | <b>4.6. X-RAY DIFFRACTION ANALYSIS</b>                   | <b>26</b> |
|          | <b>4.6.1. WORKING PRINCIPLE INVOLVED IN XRD ANALYSIS</b> | <b>26</b> |
|          | <b>4.6.2. BENIFITS AND USES OF XRD</b>                   | <b>27</b> |
|          | <b>4.7. UNIVERSAL TESTING MACHINE</b>                    | <b>27</b> |
|          | <b>4.7.1. DEFINITION OF FUM</b>                          | <b>27</b> |
|          | <b>4.7.2. COMPONENTS OF FUN</b>                          | <b>27</b> |
|          | <b>4.8. SEN-EDS</b>                                      | <b>28</b> |
|          | <b>4.8.1. DEFINITION OF SEM-EDS</b>                      | <b>28</b> |
|          | <b>4.8.2. SEM ANALYSIS</b>                               | <b>28</b> |
|          | <b>4.9. MACHINE USED</b>                                 | <b>29</b> |
| <b>5</b> | <b>RESULT AND DISCUSSION</b>                             | <b>31</b> |
|          | <b>5.1. X-RAY DIFFRACTION ANALYSIS</b>                   | <b>31</b> |
|          | <b>5.2. UNIVERSAL TESTING MACHINE RESULTS</b>            | <b>32</b> |
| <b>6</b> | <b>CONCLUSION AND SUMMARY</b>                            | <b>34</b> |
|          | <b>6.1 SUMMARY</b>                                       | <b>34</b> |
|          | <b>6.2 CONCLUSION</b>                                    | <b>34</b> |



## LIST OF FIGURES

| FIGURE<br>NO | FIGURE NAME                                                              | PAGE<br>NO |
|--------------|--------------------------------------------------------------------------|------------|
| 1.1          | SCHEMATIC DIAGRAM OF FRICTION STIR<br>PROCESSING                         | 4          |
| 1.2          | SCHEMATIC DIAGRAM OF SPARK PLASMA<br>SINTERING                           | 5          |
| 1.3          | SCHEMATIC DIAGRAM OF PRESSURE<br>INFILTRATION                            | 6          |
| 1.4          | STIR CASING SETUP WITH MUFFLE FURNACE                                    | 6          |
| 1.5          | SQUEEZE CASTING PROCESS                                                  | 7          |
| 4.1          | FLOW CHART OF ALUMINIUM REINFORCED<br>COMPOSITE                          | 20         |
| 4.2          | A MACHINE FOR PRODUCING MECHANICAL TEST<br>SPECIMEN AS PER ASTM STANDARD | 29         |
| 4.3          | A MACHINE FOR PRODUCING MECHANICAL TEST<br>SPECIMAN AS PER ASTM STANDARD | 29         |
| 4.4          | MEASUREMENT OF TENSILE/ COMPRESSION TEST<br>IN UTM                       | 30         |
| 4.5          | TENSILE/ COMPRESSION TEST IN UTM                                         | 30         |
| 4.6          | IMPACT TEST / CHARPHY TEST                                               | 30         |
| 5.1          | XRD PATTERN OF Al-SiC-TiB <sub>2</sub>                                   | 31         |
| 5.2          | STRESS-STRAIN DIAGRAM OF Al-SiC-TiB <sub>2</sub>                         | 32         |
| 5.3          | SEM MICROGRAPH OF THE FRACTURED SURFACE                                  | 33         |

## **LIST OF TABLES**

| <b>TABLE NO</b> | <b>TABLE NAME</b>                                      | <b>PAGE<br/>NO</b> |
|-----------------|--------------------------------------------------------|--------------------|
| <b>1.1</b>      | <b>COMMONLY USED REINFORCEMENT</b>                     | <b>2</b>           |
| <b>1.2</b>      | <b>PROPERTIES OF VARIOUS REINFORCEMENT</b>             | <b>3</b>           |
| <b>4.1</b>      | <b>ATOMIC DATA OF ALUMINIUM</b>                        | <b>14</b>          |
| <b>4.2</b>      | <b>THE PHYSICAL ROPERTIES OF ALUMINIUM</b>             | <b>14</b>          |
| <b>4.3</b>      | <b>THE MECHANICAL PROPERTIES OF ALUMINIUM</b>          | <b>15</b>          |
| <b>5.1</b>      | <b>MECHANICAL PROPERTIES OF Al-SiC-TiB<sub>2</sub></b> | <b>33</b>          |

## **CHAPTER – 1**

### **INTRODUCTION**

#### **1.1 INTRODUCTION TO COMPOSITE MATERIALS**

Natural composites are found in materials such as wood, which is composed of lignin and cellulose fibres. Composite materials are formed by combining two or more materials with different physical and chemical properties. The resulting properties of the composite are determined by the interactions between its constituents. People have been using composite materials for thousands of years, such as the ancient Egyptians and Mesopotamians who used mud and straw to construct strong, durable structures. Straw has also been used to reinforce other ancient composite items such as pottery and boats, and the Mongols created composite bows using animal glue, bone, and wood.

Today, composite materials are widely used in industries such as aerospace, building, and transportation. FRP composites are particularly valued for their corrosion resistance, and were first used in boats in 1946. In the automotive industry, the first composite car body was tested in 1947 and resulted in the development of innovative moulding techniques such as compression moulding and sheet moulding. Other manufacturing processes like filament winding, pultrusion, and Hoover bag moulding were developed in the early 1950s, and the marine industry remains a primary user of composite materials.

materials in the 1960s. The first carbon fibre was patented in 1961 and made commercially available many years later.

##### **1.1.1. ADVANTAGES OF COMPOSITE MATERIALS**

- Composite materials can achieve excellent strength-to-weight and stiffness-to-weight ratios, resulting in higher performance for a given weight and fuel savings.
- The mechanical qualities of composite parts can be modified by adjusting their laminate patterns and ply buildup in different directions.

- Producing smooth aerodynamic shapes that reduce drag is simpler with composites, and complicated double-curvature pieces with a smooth surface finish can be created in a single manufacturing step.
- Using composite materials can reduce part count and decrease production costs since numerous procedures can be used to create them.
- Despite the potential for damage from certain chemicals like paint remover, composites offer exceptional resistance to corrosion, chemical assault, and outside weathering. To address this, new forms of paint and stripper are being developed.

## 1.2 REINFORCEMENTS

***Table 1.1: commonly used reinforcement***

| REINFORCEMENTS                 | RELEVANT PROPERTIES                                                                                | APPLICATIONS                                                              |
|--------------------------------|----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| SiC                            | High stiffness, refractoriness, high thermal characteristics, and hardness                         | Rubber tyres, rotors, brake discs, shafts, connecting rods, pistons, etc. |
| B <sub>4</sub> C               | High hardness, chemical resistance, low weight-to-strength ratio, and high nuclear characteristics | Ballistic armour, nozzles, and abrasives                                  |
| TiC                            | Excellent wear resistance and toughness                                                            | The brake rotor, disc, and cutting equipment                              |
| Al <sub>2</sub> O <sub>3</sub> | High hardness and specific strength                                                                | Abrasives, refractory materials, and coatings                             |
| TiO <sub>2</sub>               | High tensile strength, impact strength and hardness                                                | Automotive applications                                                   |

|                  |                                                           |                                                                         |
|------------------|-----------------------------------------------------------|-------------------------------------------------------------------------|
| ZrO <sub>2</sub> | Wear and corrosion resistance and high fracture toughness | Thermal insulation, cylinder lining, connecting rods, and ceramic tubes |
| tiB <sub>2</sub> | High strength and wear resistance                         | Structure-related use in the aerospace automobile                       |
| zrB <sub>2</sub> | Thermal stability and wear resistance                     | Structural parts                                                        |

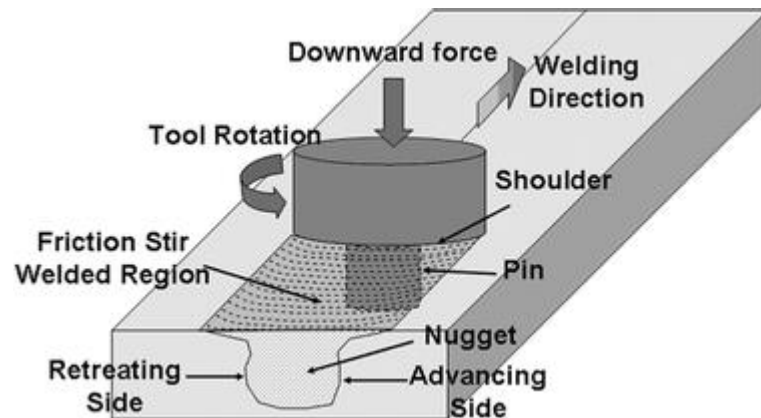
### 1.3 PROPERTIES OF VARIOUS REINFORCEMENTS

*Table 1.2: Properties of various reinforcements*

| Properties                                                | TiB <sub>2</sub> | ZrB <sub>2</sub> | TiC   | SiC       | Al <sub>2</sub> O <sub>3</sub> |
|-----------------------------------------------------------|------------------|------------------|-------|-----------|--------------------------------|
| Density(gcm <sup>-3</sup> )                               | 4.52             | 6.09             | 4.93  | 3.16      | 3.99                           |
| Melting Point (°C)                                        | 3225             | 3000             | 3067  | 1955      | 2043                           |
| Hardness, Vickers (GPa)                                   | 25-35            | 22-26            | 24-32 | 35-45     | 18-21                          |
| Modulus of elasticity (GPa)                               | 560              | 350              | 400   | 448       | 400                            |
| Thermal conductivity (W m <sup>-1</sup> K <sup>-1</sup> ) | 60-120           | 23               | 17-32 | 16-20     | 30                             |
| Crystal structure                                         | Hexagonal        | Hexagonal        | Cubic | Hexagonal | Hexagonal                      |

## 1.4 COMPOSITE MANUFACTURING TECHNIQUES

### 1.4.1. Friction stirrs processing (FSP)

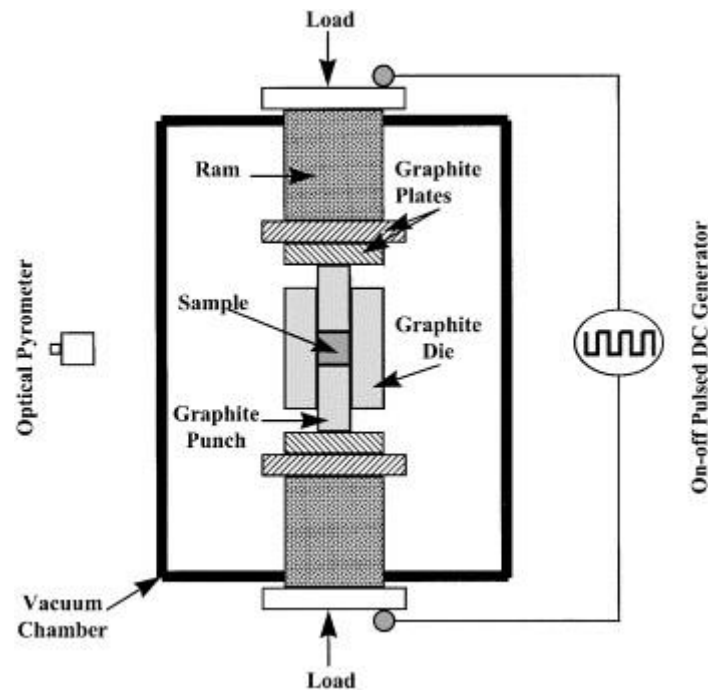


***Fig.1.1: Schematic diagram of Friction Stir processing.***

A recently created technique called FSP is utilised to prepare surface composites that give birth to finely tuned grain structures. Although it does not weld two metal plates together, it is based on the friction stir welding concept. It merely provides a change in microstructure with improved characteristics. A non-consumable tool with a shoulder and pin is agitated and inserted into the workpiece in FSP, creating a lot of friction.

As a result of the plastic movement and grain refining, the heat produced by friction softens the metals. Atul Kumar et al. demonstrated an increase in the hardness and tensile strength of AA7075/SiC nano-composite, which is produced via friction stir processing composites rather than by stir casting. Due to the FSP, the composites entirely got rid of the pores while also improving the homogeneity of the particle dispersion. Similar to this, Zhao et al. created an Al alloy plate reinforced with CNTs using the FSW technique, which resulted in homogeneous CNT dispersion and random orientation.

#### 1.4.2. POWDER METALLURGY



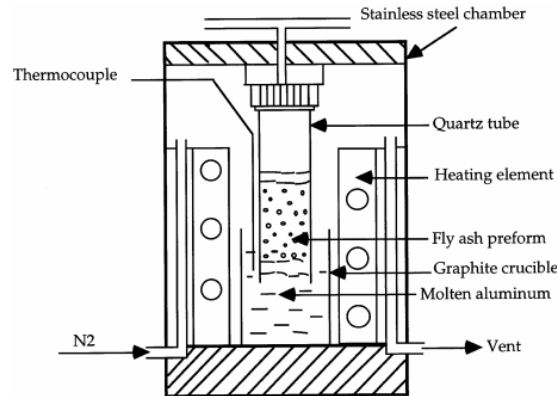
***Fig.1.2: Schematic diagram of spark plasma sintering.***

By using the spark plasma sintering (SPS) method, Cavaliere et al. reported successfully fabricating Al-SiC composites. Aluminium particles are broken during heating by the SPS process's rapid rises in pressure and temperature. The 6-weight% SiC composites were shown to have enhanced by 34% and 26% in hardness and tensile strength, respectively. According to Zhang et al., vacuum sintering at a specific temperature produced materials with the best mechanical strength and the least amount of porosity. The hardness and toughness of the sintered samples were also discovered to be influenced by the grain size and porosity.

The composite material in this method absorbs the microwave energy from the electromagnetic field and converts it to heat. The increased performance of the graphene with SiC particles was discovered. The graphene was effectively sintered to provide a lubricated solid layer, which significantly decreased wear loss. With SiC and alumina serving as reinforcing particles, Ashwath and Xavior researched the microwave sintering of Al2900 and Al2024. While alumina reinforced with Al2900 fared well in ductility and formability, SiC reinforced with AA2024 demonstrated good

strength. In comparison to composites made using alternative powder metallurgy methods, microwave-sintered composites show better mechanical characteristics.

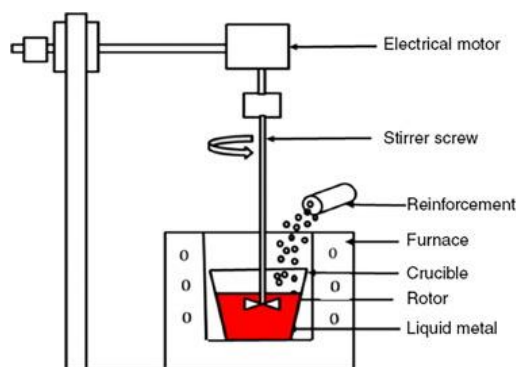
### 1.4.3. INFILTRATION METHOD



**Fig.1.3. Schematic diagram of Pressure Infiltration**

For the creation of Al-Si graphite MMCs, Narciso et al. used the pressure infiltration approach. Yang et al. investigation of graphene-reinforced Al MMCs revealed that the composite specimen's tensile strength increased after extrusion by 93%. The pressure infiltration approach created a composite of the highest quality without soaking the matrix or the reinforcement. With an increase in the composite's density, A356/fly ash cenosphere composites showed good compressive strength and modulus. The prefabricated silicon carbide fibres reinforced with SiC matrix were used in Tao and Wang's study of the vapour infiltration technique, and they reported outstanding thermal conductivity. With the aid of reactive gases at high temperatures, molten metal is infiltrated into prefabricated reinforcement during the vapour infiltration process.

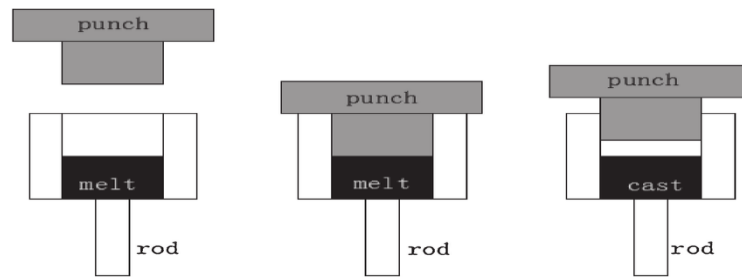
### 1.4.4. CASTING METHOD



**Fig.1.4. Stir casting setup with muffle furnace.**

The main and proven method for creating MMCs is casting. The reinforcement is combined with the molten technique to produce the appropriate casting, poured into a mould cavity, and allowed to solidify. In order to create Al-SiC composites, Soltani et al. used the stir-casting technique. They reported that increasing the stirring duration and temperature makes SiC particle integration possible. The criteria that were found to be extremely important for both the fabrication and the characteristics of MMCs were temperature, stirring time, holding duration, and the choice of reinforcing types and sizes.

By using squeeze casting to create Al/TiN composites, Lu et al. demonstrated an improvement in toughness due to ductile rupture and fracture deflection. In order to create A356/SiC composites, Gurusamy et al. used the squeeze casting method, which resulted in a fine-grain structure with minimal agglomeration.



***Fig.1.5. Squeeze casting process.***

## **1.5. COMPOSITE APPLICATIONS**

Laminar structures are the most popular type of fibre-reinforced polymer, created by stacking and connecting thin layers of fibre and polymer to achieve the required thickness. By altering the orientation of the fibres between layers in the laminate constructions, a certain level of anisotropy in the composite characteristics can be achieved. Composite materials offer many advantages, such as corrosion resistance, lightness, strength, reduced material costs, increased productivity, design flexibility, and durability, and are used in various industries for a range of applications.

### **1.5.1. AEROSPACE**

Composite materials have many potential applications in aerospace, including commercial, civilian, and military aircraft, as well as rockets and other spacecraft. In

the appliance and business industry, composite materials can be used in place of metal alloys for items such as panels, frames, and handles. Composite materials are quickly replacing traditional building materials in architecture due to their appealing aesthetics, practicality, and adaptability, and can be moulded into intricate shapes, making them more energy-efficient. The automotive industry is one of the largest markets for composite materials, and they are used to create lighter and more fuel-efficient vehicles. Composites are also used in construction, infrastructure, and in corrosive environments such as chemical processing plants and water treatment facilities. Finally, the electronics and energy industries are also adopting composite materials for their excellent dielectric properties.

### **1.5.2. SPORTS AND RECREATION**

A few outstanding qualities of composite materials include their ease of moulding, high elastic modulus, high strength, lightweight, exceptional corrosion resistance, and others. Thus, there are many uses for fibre-reinforced composite materials in the creation of sporting goods. Carbon fibres and fibreglass composite materials help athletes achieve their peak performance potential and provide strong, lightweight equipment for everything from bicycle frames to bobsleds, fishing poles, football helmets, hockey sticks, horizontal bars, jumping boards, kayaks, and rowing.

### **1.5.3. MARINE**

The primary challenge in naval architecture, just like in other branches of engineering, is to create a structure that is as light as possible. Composites are used in the marine sector to assist make hulls lighter and more damage-resistant. Marine composites are used for boat hulls, bulkheads, decks, masts, propellers, and other parts of commercial, military, and recreational ships thanks to their corrosion resistance and lightweight properties. Many more components of a nautical vessel, such as the interior mouldings and furniture on super yachts, are made of composite materials.

## CHAPTER – 2

### LITERATURE SURVEY

**One study by Ojo et al. (2020)** investigated the effect of adding  $\text{TiB}_2$  to an Al-6Ti-1.5C-0.3 Fe metal matrix composite. The addition of  $\text{TiB}_2$  led to an increase in the tensile strength and hardness of the composite, while the ductility remained relatively unchanged. The authors attributed the improvement in mechanical properties to the strengthening effect of the  $\text{TiB}_2$  particles and the refinement of the grain size.

**Another study by Ramesh et al. (2019)** explored the effect of adding  $\text{TiB}_2$  to an Al-4.5Cu-2Mg metal matrix composite reinforced with TiC. The addition of  $\text{TiB}_2$  led to an improvement in both the tensile strength and ductility of the composite. The authors suggested that the  $\text{TiB}_2$  particles.

**Fengsang Ma et al** studied Plate samples for tensile tests that were machined from the composite with 3.0 mm in thickness, 12mm in width and 50.0 mm in gauge length. Tensile tests were carried out on a Zwick/Roell 100 kN tensile testing machine. Before tests, the tensile samples were heated to test temperatures in a furnace equipped with the tensile machine and held for 5 min. The tensile tests started with a  $5.0 \times 10^{-3} \text{ s}^{-1}$  strain rate.

**P. Chandrasekhar et al** studied the laser surface treatment of Ti-34%TiB metal matrix composite leads to a substantial increase in hardness to 1050 HVN at the surface, provided that the incident energy supplied is at about 70 kJ m<sup>1</sup> or higher. There is an increase in the concentration of TiB whiskers (estimated to be about 67 vol.%) at the surface at incident energies at about 70 kJ m<sup>1</sup> or higher, possibly due to B diffusion from subsurface regions to the laser-melted region. This could explain the higher surface hardness levels. Significant hardening was also achieved at low incident energies, and the hardening depth, in all cases, reached about 0.5 mm from the surface.

In a study by **Huang et al. (2018)**, TiC alloyed aluminium metal matrix composites were reinforced with varying amounts of  $\text{TiB}_2$  particles. The addition of  $\text{TiB}_2$  led to an increase in the hardness and tensile strength of the composite, while the ductility decreased. The authors found that increasing the  $\text{TiB}_2$  content led to an increase in

the number of TiB<sub>2</sub> clusters, which acted as crack initiation sites, resulting in a decrease in ductility.

**Zhang et al. (2019)** studied the effect of TiB<sub>2</sub> reinforcement on the mechanical and tribological properties of TiC alloyed aluminium metal matrix composites. They found that the addition of TiB<sub>2</sub> particles significantly increased the tensile strength and hardness of the composite. The researchers attributed the improved mechanical properties to the strengthening effect of TiB<sub>2</sub> particles on the aluminium matrix. They also observed that the wear resistance of the composite was enhanced with the addition of TiB<sub>2</sub>, making it suitable for high-stress applications.

**Li et al. (2018)** investigated the microstructure and mechanical properties of TiB<sub>2</sub>-reinforced TiC alloyed aluminium metal matrix composites. The researchers found that the TiB<sub>2</sub> particles were uniformly distributed in the aluminium matrix, resulting in a fine-grained microstructure. The addition of TiB<sub>2</sub> particles also improved the fracture toughness and fatigue strength of the composite. The researchers concluded that TiB<sub>2</sub>-reinforced TiC alloyed aluminium metal matrix composites have the potential to be used in high-stress applications due to their improved mechanical properties.

**Zhang et al. (2017)** conducted a study on the effect of different amounts of TiB<sub>2</sub> particles on the mechanical properties of TiC alloyed aluminium metal matrix composites. They found that the addition of 5 wt% TiB<sub>2</sub> particles resulted in the highest tensile strength and hardness of the composite. The researchers also observed that the addition of TiB<sub>2</sub> particles improved the wear resistance of the composite.

One study by **Ojo et al. (2020)** of adding TiB<sub>2</sub> to an Al-6Ti-1.5Cu-0.3 Fe metal matrix composite. The addition of TiB<sub>2</sub> led to an increase in the tensile strength and hardness of the composite, while the ductility remained relatively unchanged. The authors attributed the improvement in mechanical properties to the strengthening effect of the TiB<sub>2</sub> particles and the refinement of the grain size.

Another study by **Ramesh et al. (2019)** explored the effect of adding TiB<sub>2</sub> to an Al-4.5Cu-2Mg metal matrix composite reinforced with TiC. The addition of TiB<sub>2</sub> led to an improvement in both the tensile strength and ductility of the composite. The authors suggested that the TiB<sub>2</sub> particles.

**Fengsang Ma et al** studied Plate samples for tensile tests that were machined from the composite with 3.0 mm in thickness, 12mm in width and 50.0 mm in gauge length. Tensile tests were carried out on a Zwick/Roell 100 kN tensile testing machine. Before tests, the tensile samples were heated to test temperatures in a furnace equipped with the tensile machine and held for 5 min. The tensile tests started with a  $5.0 \times 10^{-3} \text{ s}^{-1}$  strain rate.

**P. Chandrasekhar et al** studied Plate samples for tensile tests that were machined from the composite with 3.0 mm in thickness, 12mm in width and 50.0 mm in gauge length. Tensile tests were carried out on a Zwick/Roell 100 kN tensile testing machine. Before tests, the tensile samples were heated to test temperatures in a furnace equipped with the tensile machine and held for 5 min. The tensile tests started with a  $5.0 \times 10^{-3} \text{ s}^{-1}$  strain rate.

## **CHAPTER – 3**

### **AIM AND SCOPE**

#### **3.1 AIM AND SCOPE OF THE PRESENT INVESTIGATION**

- To prepare Al -10% SiC- X% TiB<sub>2</sub> composite samples using stir casting or powder metallurgy method.
- To evaluate the surface topography of the samples using optical microscopy, scanning electron microscopy, and Atomic-force microscopy and obtain their density and porosity.
- To evaluate their structural arrangement using XRD analysis and SEM-EDS.
- To obtain the mechanical properties of the samples using a microhardness test, scratch test, tensile test, and impact test.

## **CHAPTER – 4**

### **MATERIALS AND METHODOLOGY**

This chapter describes the details of the processing of the composites and the experimental procedures followed by their mechanical characterisation.

#### **4.1. MATERIALS USED**

- Aluminium powder – Al (20-40µm)
- Silicon Carbide powder – SiC (20-40µm)
- Titanium di-boride powder – TiB<sub>2</sub> (20-40µm)

##### **4.1.1. ALUMINIUM POWDER**

Aluminium as matrix material. Aluminium metal matrix composites are lightweight, highly resistant to corrosion, and very durable, making them ideal for use in a variety of industries such as automotive, aerospace, and marine. Different techniques like stir casting, squeeze casting, compo casting, powder metallurgy, and in situ synthesis have been used to create aluminium MMCs such as the 6061, 7075, and 5058 series. To improve their mechanical and tribological properties, reinforcements such as Al<sub>2</sub>O<sub>3</sub>, silicon carbide, fly ash, zircon, and boron carbide have been added. The distribution of these reinforcements affects the characteristics of the composite. These materials are created by combining the aluminium matrix phase and the reinforcements phase. Metal matrix composites are used to make aerospace components, missiles, jets, and cutting tools. The goal is to combine the positive qualities of metals and ceramics. Aluminium alloys are widely used in aerospace and automotive industries due to their low density, excellent mechanical qualities, and resistance to corrosion and wear. The review study examines the effect of various reinforcements on aluminium alloys and their benefits and drawbacks. The study aims to encourage further research on creating aluminium metal matrix composites with minimal reinforcements.

#### 4.1.2. ATOMIC DATA OF ALUMINIUM

**Table 4.1: Atomic data of Aluminium**

|                                                              |        |
|--------------------------------------------------------------|--------|
| Atomic radius, non-bonded (Å)                                | 1.84   |
| Covalent radius (Å)                                          | 1.24   |
| Electron affinity (kJ mol <sup>-1</sup> )                    | 41.762 |
| Electronegativity (Pauling scale)                            | 1.61   |
| Specific heat capacity (J kg <sup>-1</sup> K <sup>-1</sup> ) | 897    |
| Young's modulus (GPa)                                        | 70.3   |
| Shear modulus (GPa)                                          | 26.1   |
| Bulk modulus (GPa)                                           | 75.5   |

#### 4.1.3. PHYSICAL PROPERTIES OF ALUMINIUM

**Table 4.2: The physical properties of Aluminium**

|                  |                                                                                                      |
|------------------|------------------------------------------------------------------------------------------------------|
| Colour and state | Silvery-white with a little bluish hue, solid, nonmagnetic, and non-lustrous.                        |
| Structure        | Up until its melting point, aluminium maintains its face-centred cubic form.                         |
| Surface          | They are highly reflective                                                                           |
| Hardness         | Pure aluminium used in commercials is brittle. When it is alloyed and tempered, it becomes stronger. |
| Ductility        | Extremely ductile. Aluminium may be very thinly hammered.                                            |
| Malleability     | The high degree of malleability. Aluminium can be moulded or bent extremely easily.                  |

|                                 |                                                                                                                                                                           |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Thermal expansion               | The thermal expansion coefficient of aluminium is 23.2. This is a comparison between steel, which expands over half the range of aluminium, and zinc, which expands more. |
| Conductivity                    | A good thermal and electrical conductor                                                                                                                                   |
| Density                         | Aluminium has a low density of 2.70 when compared to water as determined by gravity. Contrast this with the density of iron/steel, which is 7.87.                         |
| Melting point and Boiling point | The melting and boiling points of commercially pure aluminium are respectively 1220°F and 4,478°F. Once aluminium is alloyed, this changes.                               |

#### 4.1.4. MECHANICAL PROPERTIES

***Table 4.3: The mechanical properties of Aluminium***

|                           |                                                                                                                    |
|---------------------------|--------------------------------------------------------------------------------------------------------------------|
| Elasticity in tension     | The Young's modulus of aluminium is 10,000 ksi. This is in comparison to wood at 1595 ksi. or copper at 17550 ksi. |
| Ultimate tensile strength | 13,000 Psi                                                                                                         |
| Yield strength            | 5,000 Psi                                                                                                          |
| Bearing yield strength    | 23100 Psi                                                                                                          |
| Elongation at break       | 15-28%                                                                                                             |
| Shear Strength            | 9000 Psi                                                                                                           |
| Fatigue strength          | 5000 Psi                                                                                                           |

#### 4.1.5. ADVANTAGES OF ALUMINIUM

The benefits of aluminium as a material are related to the exceptional qualities listed below, which can be used universally in practically all industries and for every application. This has led to all of aluminium's benefits as a material becoming a crucial element in manufacturing and building.

**Resistance to corrosion:** As was previously mentioned, aluminium that has been exposed to moisture and air develops a protective surface oxide layer that resists corrosion. Aluminium is used in a range of industrial and construction settings, as well as in kitchen furnishings and the automotive industry because it degrades more slowly as a result. Due to its inherent fire resistance, aluminium makes a great building material for both residential and commercial structures.

**Thermal and electrical conductivity:** Aluminium is a good conductor of both heat and electricity. It conducts up to 60% of its normal value while being three times lighter than copper. Due to these characteristics, aluminium is widely used as a copper substitute in the chemical, food, and aviation industries. Modern aluminium with a polyamide thermal break creates a barrier between the heat within and the cold outside, keeping as much heat inside the building as possible

**Reflectivity:** Aluminium has a high reflectivity over the entire electromagnetic spectrum, including that of heat and sunshine. Its characteristics are crucial for aluminium shutters since they reflect up to 80% of sunlight and 90% of the heat that hits their surface. Aluminium's reflection enhances the visual.

**Nontoxicity:** Because it is harmless, aluminium is employed in the food business and in environments where cooking takes place. In terms of the shutters, this is a better option than PVC-made ones.

**Ductility:** Aluminium is readily malleable and may be cast into a wide range of shapes, diameters, and widths. It offers solutions for all kinds of technically challenging design, architectural, and building projects and is used in aluminium joinery.

**Simple finishing:** Another advantage of utilising aluminium is the flexibility and simplicity of the finishing options. Although aluminium can be given extra protective

coatings and qualities through a variety of processes like polishing, sandblasting, brushing, painting, and employing chemical and electrochemical procedures, it is still useful and flexible on its own.

***Versatility of production and application:*** Aluminium's ease of manufacture in both its pure and mixed states utilising any casting, processing, and moulding technique is another benefit of the material. The manufacture of the smallest wires, foils, and sheets, as well as big and colossal constructions, demonstrates a high level of industrial adaptability.

***The exceptional value of recycling:*** Recyclability is a key component of aluminium's benefits as a material. Aluminium may be melted, reformed, and used for new projects because of its low melting point. Compared to the manufacture of new aluminium, it can be recycled up to 100% of the time with only 5% of the energy. Although there are certain differences between new and recycled aluminium in terms of its attributes, it retains its fundamental physical characteristics and can thus be used dependably in all projects that call for sustainability without sacrificing the product's durability. At the end of its lifecycle, 60% of aluminium is currently recycled, making it the most recyclable material available.

***Stability at low temperature:*** Its stability at low temperatures is another factor in its efficient and ideal application. Aluminium and its alloys get increasingly stronger, while other metals become brittle. It exhibits better tensile strength, hardness, impact resistance, and corrosion resistance at low temperatures.

***Impermeability:*** Aluminium is distinguished by its exceptional aroma and flavour impermeability. It is utilised in foods, drinks, and pharmaceutical products all for this reason. When used in bigger shapes and components, like shutters, aluminium's impermeability property becomes active at a minimum width of 0.007 mm, providing extra protection for your structure against smells, tastes, moisture, and UV radiation.

***Para magnetism:*** Aluminium is distinguished by its exceptional aroma and flavour impermeability. It is utilised in foods, drinks, and pharmaceutical products all for this reason. When used in bigger shapes and components, like shutters, aluminium's impermeability property becomes active at a minimum width of 0.007 mm, providing extra protection for your structure against smells, tastes, moisture, and UV radiation.

**Sound and impact absorption:** The soundproofing of all the buildings where aluminium shutters is installed is improved because aluminium is a good material for noise reduction. A further aspect of protection is resistance to impact. The impact on porosity and thickness, as well as various composition treatments, can be used to enable sound and impact transmission when utilising aluminium foam, if necessary.

**Low weight:** Due to its strength and low specific weight of 2.7 g/cm<sup>3</sup>, aluminium ensures low production costs, reduced weight when used, and maintains application usefulness and load capacity. It is a practical material that works well for many different uses. It creates openings that are bigger and more useful, with improved characteristics and less weight, which has a good impact on the building's complete structure.

## **4.2. SILICON CARBIDE POWDER**

### **4.2.1. SILICON CARBIDE AS REINFORCEMENT**

Silicon carbide powder is one of the two reinforcements. A hard chemical compound made of silicon and carbon is called silicon carbide (SiC), sometimes known as carborundum. Since 1893, it has been mass-produced as a powder and crystal for use as an abrasive. It is a semiconductor that naturally occurs as the incredibly uncommon mineral moissanite. Sintering is a process that bonds silicon carbide grains together to create extremely hard ceramics, which are frequently used in high-endurance applications including vehicle brakes, car clutches, and ceramic plates in bulletproof vests. The Lely process can be used to create large silicon carbide single crystals, and these crystals can then be carved into gems called synthetic moissanite.

Only trace amounts of moissanite are found in certain types of kimberlites, corundum deposits, and meteorites that are naturally occurring. All silicon carbide sold worldwide, including moissanite jewellery, is essentially synthetic.

Silicon carbide is quite plentiful in space, despite being uncommon on Earth. It is a typical type of stardust found in the vicinity of carbon-rich stars, and samples of this stardust have been discovered in undamaged, early meteorites. were examined, and the results showed aberrant carbon and silicon isotope ratios, suggesting that these grains came from outside the solar system.

## 4.3. TITANIUM DI-BORIDE

### 4.3.1. MATERIAL DESCRIPTION

The earth does not naturally contain  $\text{TiB}_2$ . Numerous high-temperature processes, such as carbothermal reduction by thermite reaction of titanium oxide and boron oxide, hydrogen reduction of boron halides in the presence of the metal or its halides, or direct reactions of titanium or its oxides/hydrides with elemental boron over  $1000^\circ\text{C}$ , can produce titanium diboride powder. In addition to other synthesis methods, electrochemical synthesis and solid-state processes have been developed to produce larger amounts of finer titanium diboride. The boro thermic reduction is an illustration of a solid-state reaction and can be seen in the following reactions:

The many techniques used to create the material are as follows.

- $\text{NaBH}_4$  and  $\text{TiCl}_4$  react in solution, and the resulting amorphous precursor is then heated to between  $900$  and  $1100^\circ\text{C}$  for annealing.
- Metal powders of Ti and B are mechanically alloyed.
- Self-propagating high-temperature synthesis method using different NaCl addition rates.
- Self-propagating high-temperature synthesis with milling assistance.
- At  $400^\circ\text{C}$ , metallic sodium undergoes a solvothermal reaction with amorphous boron powder and  $\text{TiCl}_4$ .



### 4.3.2. POTENTIAL TITANIUM DI-BORIDE APPLICATIONS

- $\text{TiB}_2$ 's current applications seem to be restricted to a small number of specialised fields, including wear-resistant coatings, crucibles, impact-resistant armour, and cutting tools.
- $\text{TiB}_2$  is often used in aluminium vapour painting evaporation boats. It is a desirable substance for the aluminium industry because of its wettability, poor solubility in molten aluminium, and strong electrical conductivity to refine the grain size while casting aluminium alloys.
- A inexpensive and/or durable substrate can be given wear and corrosion resistance using thin layers of  $\text{TiB}_2$ .

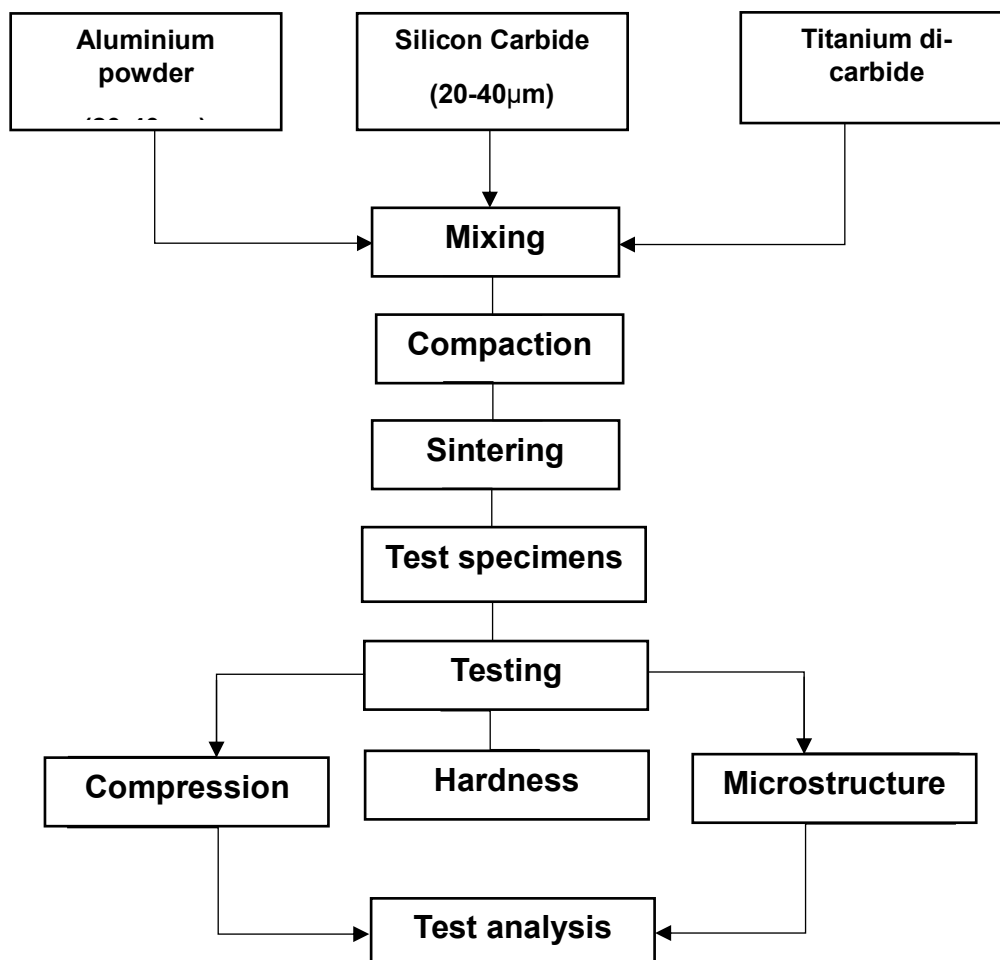
- Economical barriers, particularly the price of densifying a material with a high melting point like titanium dioxide, which has a melting temperature of roughly 2970 °C and is very resistant to sintering, prevent many applications of TiB<sub>2</sub> from being used.

Therefore, these reinforcements are taken and reinforced with Aluminium to form Aluminium-Metal-Matric Composite.

#### 4.4. METHODOLOGY

The methodology flow chart is shown in the figure in order to achieve the objectives of this project and is listed below.

##### 4.4.1. METHODOLOGY FLOW CHART



**Fig.4.1: Flow chart of Aluminium Reinforced Composite**

#### **4.4.2. OBJECTIVES**

- To prepare Al-10%SiC-X%TiB<sub>2</sub> composite samples using the powder metallurgy method.
- To evaluate the surface topography of the samples using optical microscopy, scanning electron microscopy, and atomic force microscopy.
- To evaluate their structural arrangement using XRD analysis and SEM-EDS.
- To obtain the mechanical properties of the samples using a microhardness test, scratch test, tensile test and impact test.

#### **4.4.3. POWDER METALLURGY**

Powder metallurgy is a manufacturing process that creates precise and very accurate parts by applying tremendous pressure to press powdered metals and alloys into a hard die. Powder metallurgy has evolved into a crucial technique for the creation of bushings, bearings, gears, and a variety of structural components as a result of the development and use of technological advancements.

The sintering process, which involves heating components to join powder particles, is essential to the accuracy and success of powder metallurgy. Sintering occurs at a temperature that is just below the primary metal's melting point, which causes the bonds between the powdered particles to solidify.

An age-old, one-of-a-kind technique for shaping and creating designs out of ferrous and non-ferrous metals is called powder metallurgy. Tools and household goods have been made using powder metallurgy for thousands of years. In the midst of the first industrial revolution, it started as a technique for mass-producing goods and components.

The procedure was occasionally employed up until the early 20th century, but it was not regarded as a practical means of manufacturing. Powder metallurgy has established itself as a very effective and productive technology for making parts with high tolerances and little waste as a result of the development of electricity and technical advancements. The preparation of the powder, mixing and blending, compacting, and sintering are the four fundamental processes in the powder

metallurgy process. These procedures have been utilised for ages to create a wide range of goods.

Powder metallurgy includes modifications to meet the needs of certain parts, just like any production process. Engineering standards and technical developments have led to the development of many approaches and procedures. Conventional, injection moulding, isostatic pressing, and metal additive manufacturing the most recent development are the other four kinds.

#### **4.4.4. BENEFITS OF POWDER METALLURGY PROCESS**

Many people might think that the stages involved in the powder metallurgy process are a waste of time when there are quicker alternatives. Despite certain drawbacks, powder metallurgy is one of the most widely used production techniques due to its many advantages.

The manufacturing of homogeneous, uniform parts with remarkable tolerances at high efficiency and low cost is a key component in the manufacture of metal products. These factors have contributed to the importance of powder metallurgy in the production of cars and aeroplanes.

***Eco-Friendliness:*** An environmentally friendly production technique is powder metallurgy. Using powder metallurgy, an incredible 97% of the material needed to make the pieces ends up in the finished product. There is virtually little waste and no scrap in powder metallurgy. The final component contains every particle of powder that was used in the procedure. Not only is there less waste, but there are also huge financial savings.

***Flexibility:*** Powder metallurgy, in contrast to other procedures, may combine and blend several metals and nonmetals into a product. With the use of binding material, strange and unusual combinations can be combined to form a single part. Because powder metallurgy can simply blend many elements and crush them into a single shape, complicated metallurgical techniques can be avoided.

Powder metallurgy has the ability to create any shape, including simple gears as well as complicated and complex designs. The door to new and varied applications is being opened by the technology's ongoing development.

**Near Net Shape:** Powder-metallurgy-generated parts and goods don't need any additional processing. Each component is almost in net shape, so finishing is not necessary. Powder-metallurgy parts also have incredibly high dimensional precision.

**Raw materials:** Since a scarcity of resources can cause production to slow down or stop, the availability of raw materials is a persistent issue for manufacturing processes. Powder metallurgy can use readily available and reasonably priced raw materials. Metal powders are a relatively common and everyday material that is easily accessible from numerous producers. As demand for powder metallurgy increased, more suppliers created fabrication procedures to satisfy it.

**Repeatability:** Every component in mass manufacturing must, from the very first one to the very last, adhere to the dimensional specifications specified in the design. The degradation that happens during production in some procedures results in flaws and variations in the individual parts. Such mistakes are prevented by the consistency and reproducibility of the powder metallurgy process, which also guarantees that each item has accurate dimensions.

**Wear Resistance:** To save expensive repairs and replacements, it's critical that parts placed in vehicles, aircraft, and machinery have a long-life lifetime. Powder metallurgy parts have outstanding wear resistance and friction coefficient. These elements ensure the durability of a powder metallurgy component after installation.

**Magnetism:** The capability of powder metallurgy to construct and produce magnetic components while also controlling the magnetic characteristics is one of its distinctive features. It is simple to add this attribute to powder metallurgy parts because the procedure for producing magnets is the same as that used to compact powder material.

**Chemical Homogeneity:** If a substance is homogenous, its composition will remain constant no matter where you take a sample. This trait shows that a part's characteristics are constant throughout its structure. For a component to have

uniformity, strength, and durability, chemical homogeneity is necessary. This feature is shared by all powder metallurgy products, which explains why they endure so long.

## **4.5. TESTING**

### **4.5.1. DESTRUCTIVE AND NON-DESTRUCTIVE TESTING**

#### **4.5.1.1. DESTRUCTIVE TESTING**

Destructive testing, also known as DT, is a method of testing used to pinpoint the exact point of failure of materials, machines, or machine parts. The object being tested is subjected to stress during the process, eventually causing the material to deform or break down. Once materials or components have gone through destructive testing, they cannot be used again for regular operation.

Usually, destructive testing is performed before a component is mass-produced. Original Equipment Manufacturers (OEMs) must be aware of their product's limitations to provide proper maintenance and operating instructions for their machines.

Specialized scientists, researchers, and technicians conduct destructive testing, depending on the type of testing required. The following experts typically perform destructive testing: Destructive testing is typically carried out by:

- Material scientists specializing in metallurgy, polymers, and other materials
- Experts in chemistry and electrochemistry
- Failure analysis experts
- Quality assurance specialists
- Regulatory compliance experts.

While this list is not exhaustive, it gives an idea of the level of knowledge required to carry out destructive testing and the purpose of the testing.

#### **4.5.1.2. THE NEED FOR DESTRUCTIVE TESTING**

The testing processes cause harm to materials that are subjected to destructive testing. Destructive testing does, however, have many valid applications. Destructive testing and the use of materials with particular properties are frequently mandated by regulations.

The fact is that some physical and chemical properties of machines and materials make them unsuitable for all environments. For instance, in excessively humid settings, it is not advisable to employ metals that corrode easily.

Even well-known consumer brands like Apple are guilty of neglecting to test the robustness of their product designs. Poor bend testing performed by their engineers or contractors led to the bend gate incident, which revealed that the iPhone 6 and 6s were prone to bending in small pockets.

#### **4.5.1.3. DESTRUCTIVE TESTING BENEFITS**

Destructive testing has a lot of benefits. They consist of the following:

Verifies a material's characteristics; evaluates the weld quality aids in lowering failures, accidents, and expenses

- Assesses impact resistance.
- Examines ductility
- May reveal information regarding yield and ultimate tensile strength, fracture toughness, and fatigue strength.
- Can play a significant role in engineering important evaluations.
- Characterizes the materials
- Identifies fabrication validity
- Forecasts service life

Additionally, it enables you to examine the objects at the molecular level in order to pinpoint an object's precise chemical makeup.

#### **4.5.2. NON-DESTRUCTIVE TESTING**

##### **4.5.2.1. DEFINITION OF NON-DESTRUCTIVE TESTING**

Non-destructive testing (NDT) is a field that combines materials science with quality control. It involves the inspection and evaluation of materials, components, or assemblies without causing any damage to their usability. NDT techniques can identify improperly constructed subcomponents as well as various types of defects such as cracks, voids, inclusions, and weld discontinuities. The use of NDT is critical for regulating industrial processes, maintaining product integrity and dependability, reducing production costs, and ensuring a consistent quality standard. Failure to use

NDT can significantly compromise the safety and reliability of components, leading to catastrophic incidents such as shipwrecks, pipeline leaks and explosions, plane and train disasters, and nuclear reactor failures. Industries that rely on NDT include aerospace, manufacturing, energy (including oil and gas and nuclear), chemical, infrastructure (such as bridges, highways, and buildings), transportation (including automotive and railways), maritime, and construction.

#### **4.5.2.2. SAVING WITH NDT**

In a number of ways, NDT helps businesses save time and money.

**Minimized Waste:** NDT techniques preserve chemicals and allow their continued use, resulting in reduced sample waste.

**Reduced Downtime:** Some testing methods enable materials to be tested while they are still in use, eliminating the need to stop activities and reducing idle time.

**Prevention of Accidents:** Non-destructive testing can help prevent accidents, which can lead to maintenance costs, equipment replacement, and business closure.

**Early Detection of Problem Areas:** NDT can detect areas of concern before they become problematic, preventing unplanned business closures or disasters and reducing the cost of fixing or replacing components.

**Comprehensive Testing:** NDT can evaluate every component or product without altering the substances being tested, eliminating the need for selective sampling. NDT can also be used at various stages of production to identify and address defective parts.

**Improved Product Reliability:** Thorough and advanced testing ensures better product quality. NDT can identify and resolve issues before a product enters the market, and ongoing testing can maintain product functionality.

### **4.6. XRD ANALYSIS**

#### **4.6.1. WORKING PRINCIPLE INVOLVED IN XRD ANALYSIS**

The majority of directions experience destructive interference when these waves interact, but Bragg's law reveals that there are a few directions where they add up constructively. This law is expressed by the equation  $2d\sin\theta = n\lambda$ , where  $d$  is the

distance between diffracting planes,  $\theta$  is the angle of incidence,  $n$  is an integer, and  $\lambda$  is the wavelength of the beam. When electromagnetic waves strike a regular array of scatterers, reflections are produced that correspond to precise directions in the diffraction pattern. X-ray diffraction patterns are generated as a result of X-rays having a wavelength that is often similar to the distance,  $d$ , between the surfaces of the crystal (which can range from 1 to 100 angstroms), making them a useful tool for creating these patterns.

#### **4.6.2. BENEFITS AND USES OF XRD**

- A non-destructive method for identifying crystalline phases and orientation is XRD.
- Identify structural characteristics like
- Parameters for a lattice
- Grain size, epitaxy, strain, and phase composition
- Favourable orientation
- Measure the thickness of many layers and thin films.
- Identify the atomic configuration.
- 

### **4.7. UNIVERSAL TESTING MACHINE**

#### **4.7.1. DEFINITION OF UTM**

The tensile strength and compressive strength of materials are tested using a universal testing machine (UTM), often referred to as a universal tester, materials testing machine, or materials test frame. A tensiometer is a former term for a tensile testing device.

#### **4.7.2. COMPONENTS OF UTM**

The load frame is composed of a pair of durable machine supports, although smaller machines may only have one. A load cell is necessary to measure the force applied to the load frame and it is recommended to periodically calibrate it to ensure accuracy, as per quality or regulatory standards. The crosshead is responsible for moving up and down and is controlled to maintain a constant speed, known as a CRE (constant rate of extension) machine, with some models offering programmable speeds and

various types of drives (resonant, linear, electromechanical). The production of test results requires a specific device, which may include chart recorders, digital displays, or computer interfaces for analysis and printing, depending on the machine's age and features. Conditioning is necessary for many tests, with temperature, humidity, and pressure being some of the factors that can be controlled through a customized environmental chamber or a controlled space

## **4.8. SCANNING ELECTRON MICROSCOPY / ENERGY DISPERSIVE SPECTROSCOPY (SEM-EDS)**

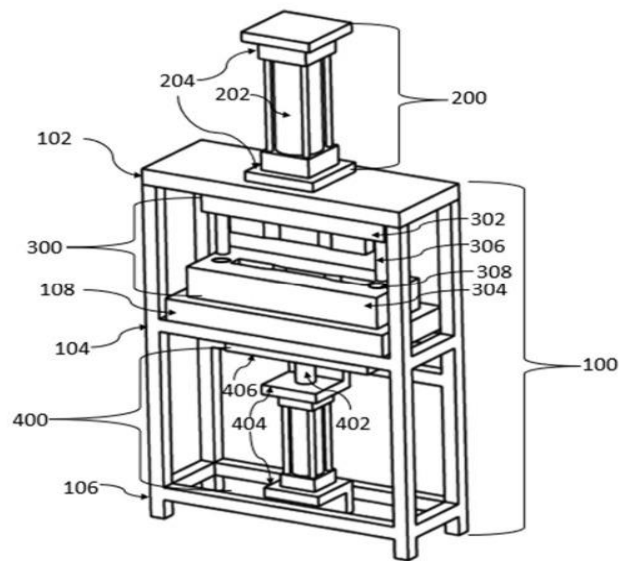
### **4.8.1. DEFINITIONS OF SEM-EDS**

SEM analysis, which involves using a powerful electron beam to produce detailed images of a material's surface, is an effective method for investigating surface fractures, defects, impurities, and corrosion. Our metallurgical experts use this technique in conjunction with EDX analysis to thoroughly evaluate the properties of materials and provide valuable information to manufacturers. EDX analysis is a complementary technique that allows our specialists to perform more detailed examinations of specific areas of interest in a sample after it has been analyzed using SEM.

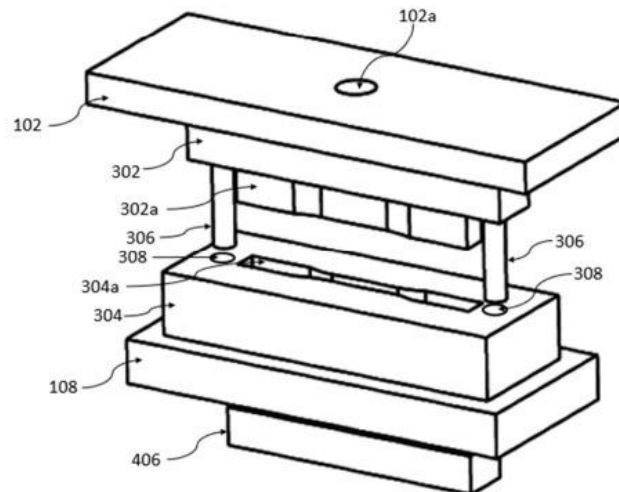
### **4.8.2. SEM ANALYSIS**

The technique of scanning electron microscopy is employed to inspect surfaces and identify any impurities or unknown particles, as well as investigate the causes of failures and interactions between various materials. This analysis is useful in examining particles like wear debris formed during mechanical wear tests, as well as evaluating surfaces. With its high magnification and resolution, SEM analysis allows for the determination of the amount, dimensions, and structure of microscopic particles, thus helping clients understand the wear properties of their material.

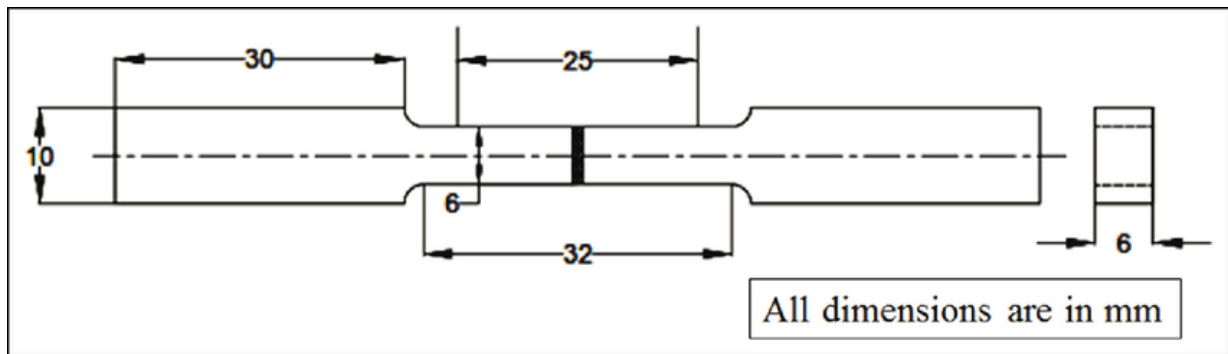
## 4.9. MACHINES USED



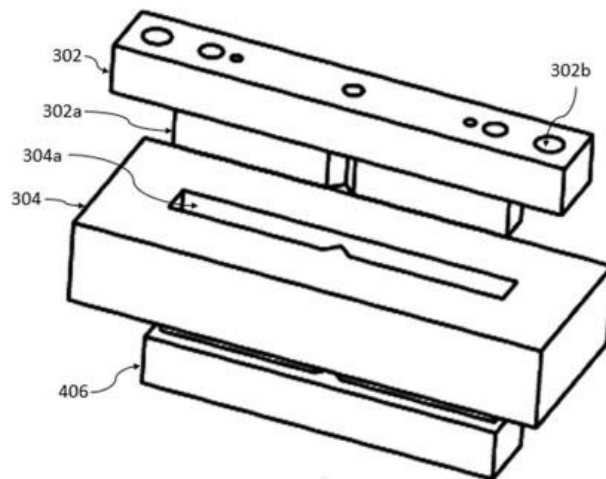
***Fig.4.2: A machine for producing mechanical test specimens as per ASTM standard***



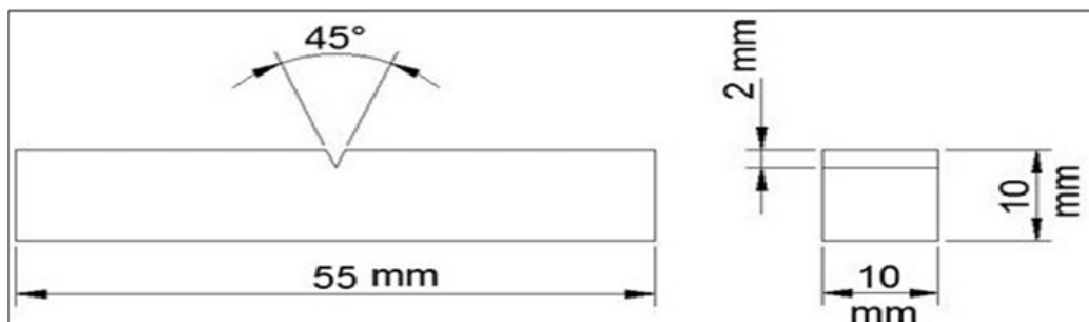
***Fig.4.3: A machine for producing mechanical test specimens as per ASTM standard***



**Fig.4.4: Measurement of Tensile/compression test in UTM**



**Fig.4.5: Tensile/compression test in UTM**



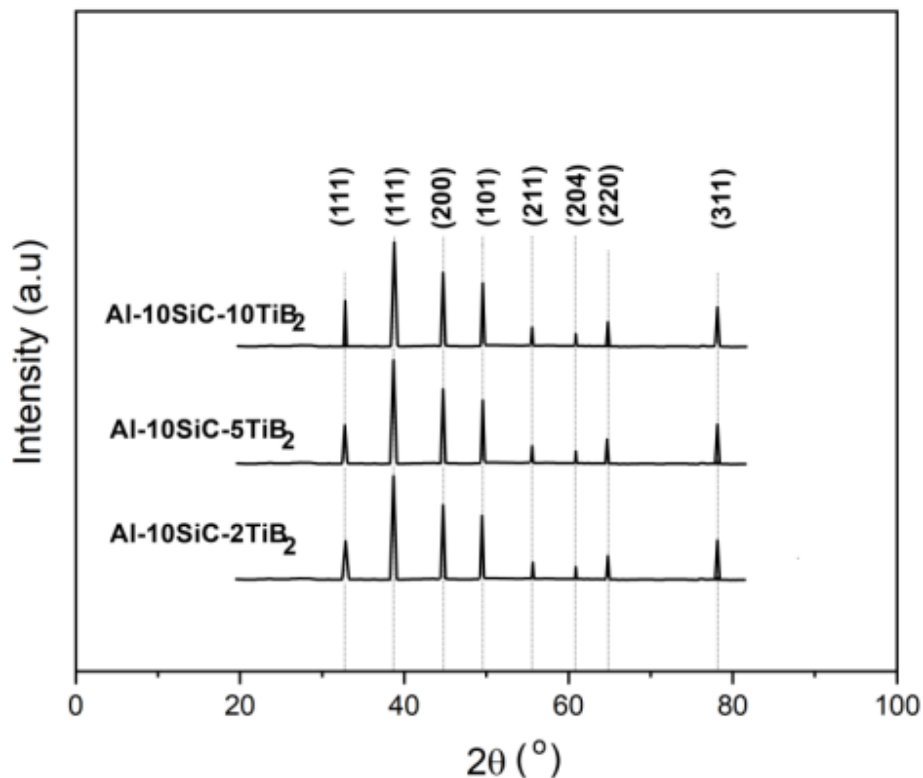
**Fig.4.6: Impact test / Charpy test**

## CHAPTER – 5

### RESULTS AND DISCUSSION

#### 5.1. XRD DIFFRACTION ANALYSIS

The outcomes of the X-Ray Diffraction analysis (XRD analysis) are as follows. The composition of SiC is kept constant-10% throughout the project. The  $\text{TiB}_2$  is taken in different compositions, we kept on increasing its composition starting from 2% and obtained three samples.



**Fig.5.1: XRD pattern of Al-SiC-TiB<sub>2</sub> composites**

**Al peaks:** 38.33° (111), 42.48° (200), 77.91° (311) in accordance with JCPDS card # 04-0787

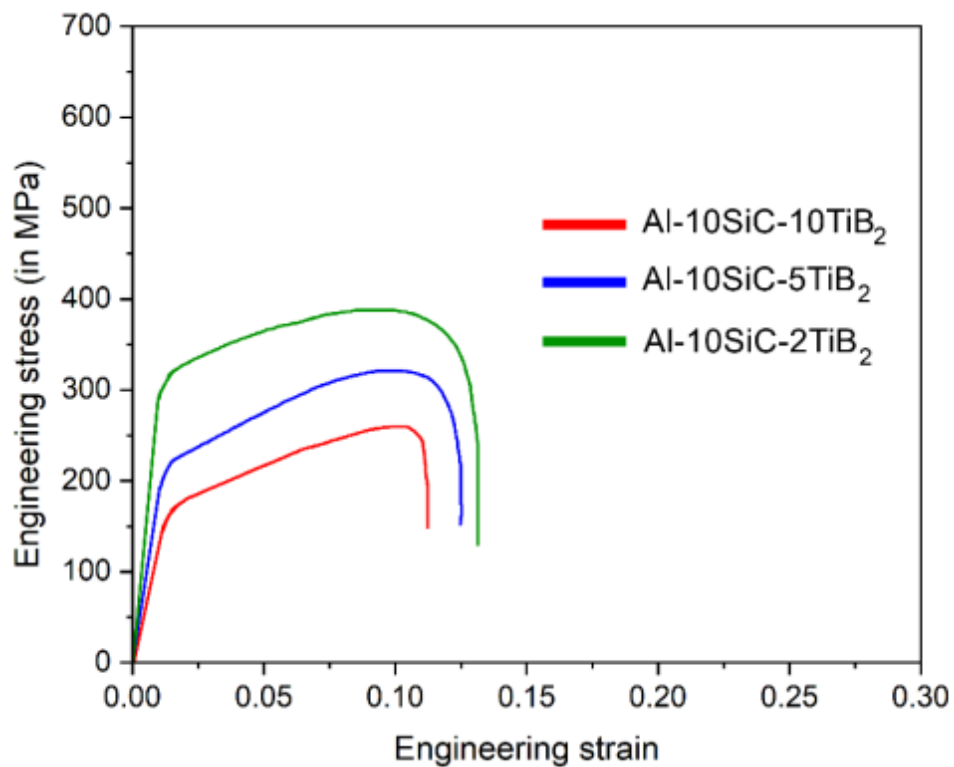
**SiC peaks:** 44.56° (200), 65.56° (220) in accordance with JCPDS card # 00-029-1129

**TiB<sub>2</sub> peaks:** 34.12° (111), 56.23° (211), 62.36° (204) in accordance with JCPDS card # 35-0741

The peaks are observed for all three materials (Al, SiC, TiB<sub>2</sub>) and explained using a graph in accordance with JCPDS software. Every peak of the material has its orientation and incident angle and different card numbers in order to identify the exact position of the plane. The scanning range is between 20 to 80 degrees. There's a slight increase in peaks as we increase the composition of TiB<sub>2</sub> and also, we can observe the width of the peak is decreasing, (the peak is getting narrower as we increase the composition of TiB<sub>2</sub>) which means the crystallite size of the sample is decreasing accordingly (The crystals inside are getting finer).

According to the Hall-Petch effect, it says that the finer grains induce better hardness. Therefore, increasing the composition of one of the reinforcements (here TiB<sub>2</sub>) results in better hardness of the sample (Al-10SiC-TiB<sub>2</sub>)

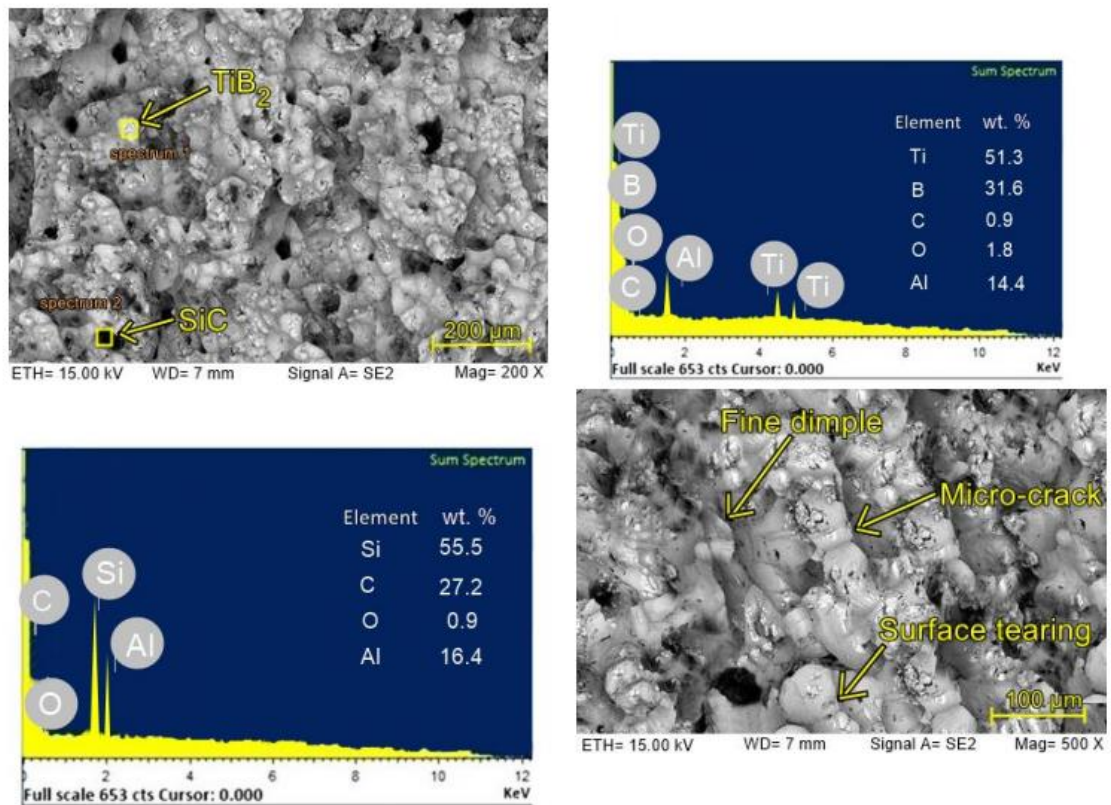
## 5.2. UNIVERSAL TESTING MACHINE RESULTS



**Fig.5.2: Stress-Strain diagram of Al-SiC-TiB<sub>2</sub> composites**

**Table 5.1: Mechanical properties of Al-SiC-TiB<sub>2</sub> composites**

| <b>Metal matrix composites</b> | <b>UTS<br/>(in MPa)</b> | <b>0.2% YS<br/>(in MPa)</b> | <b>Ductility<br/>(%)</b> | <b>Vickers<br/>microhardness</b> |
|--------------------------------|-------------------------|-----------------------------|--------------------------|----------------------------------|
| Al-10SiC-2TiB <sub>2</sub>     | 227                     | 149                         | 8.4                      | 95                               |
| Al-10SiC-5TiB <sub>2</sub>     | 311                     | 221                         | 10.8                     | 127                              |
| Al-10SiC-10TiB <sub>2</sub>    | 362                     | 319                         | 12.1                     | 159                              |



**Fig.5.3: SEM micrograph of the fractured surface showing (a) SiC and TiB<sub>2</sub> particles and their (b-c) corresponding EDS spectrum and (d) fracturing methods.**

## **CHAPTER – 6**

### **CONCLUSION AND SUMMARY**

#### **6.1. SUMMARY**

The need for high-performance and affordable materials has led researchers worldwide to shift their focus from monolithic materials to composite materials. Recently, much effort has been dedicated to creating different combinations of metal matrix composites. Among these, aluminium-based composites are considered the most promising structural materials for automotive and aerospace applications due to their high corrosion resistance, wear resistance, specific modulus, and lightweight. Various reinforcement particles, such as borides, carbides, oxides, and nitrides, have been used to produce aluminium MMCs through different manufacturing processes. These composites have demonstrated good mechanical and wear properties due to the stable reinforcement particles within them. The current report discusses the latest advancements in processing, microstructure, wear, and mechanical characterization of aluminium composites with different particles.

#### **6.2. CONCLUSION**

- The peaks are observed for all three materials (Al, SiC, TiB<sub>2</sub>) and explained using a graph in accordance with JCPDS software.
- Every peak of the material has its orientation and incident angle and different card numbers in order to identify the exact position of the plane. The scanning range is between 20 to 80 degrees.
- There's a slight increase in peaks as we increase the composition of TiB<sub>2</sub> and also, we can observe the width of the peak is decreasing, (the peak is getting narrower as we increase the composition of TiB<sub>2</sub>) which means the crystallite size of the sample is decreasing accordingly (The crystals inside are getting finer).
- According to the Hall-Petch effect, it says that the finer grains induce better hardness. Therefore, increasing the composition of one of the reinforcements (here TiB<sub>2</sub>) results in better hardness of the sample (Al-10SiC-TiB<sub>2</sub>)

- The mechanical properties of the composite material Al-SiC-TiB<sub>2</sub> have increased with the increase in the composition of TiB<sub>2</sub>. Therefore, by adding this Titanium di-boride as reinforcement in this Aluminium composite.
- The properties were determined and compared. As we can see from the results, each mechanical property was enhanced. Mechanical properties include Ultimate tensile strength, Yield strength, Ductility, and Vickers hardness.
- Therefore, it is clear that composite materials made human life easier because of their extremely good properties and numerous applications which are used in daily.

## REFERENCE

- [1] Taha MA. Industrialization of cast aluminium matrix composites (AMCCs). Mater. Manuf. Process. 2001;16(5):619–41. <https://doi.org/10.1081/AMP-100108625>
- [2] Kim CS, Cho K, Manjili MH, Nezafati M. Mechanical performance of particulate-reinforced Al metal-matrix composites (MMCs) and Al Metal-Matrix Nano-Composites (MMNCs). J Mater Sci 2017; 52:13319–49. <https://doi.org/10.1007/s10853-017-1378-x>
- [3] Anthony M, Schultz BF, Rohatgi PK, Gupta N. In: Elmarakbi A, editor. Metal matrix composites for automotive applications. John Wiley & Sons; 2014. <https://doi.org/10.1002/9781118535288>
- [4] Bhoi NK, Singh H, Pratap S. Developments in the aluminium metal matrix composites reinforced by micro/nano particles – a review. J Compos Mater 2020; 54(6):813–33. <https://doi.org/10.1177/0021998319865307>
- [5] Macke A, Schultz BF. Metal matrix composites offer the automotive industry and opportunity to reduce vehicle weight, improve performance. Adv. Mater. Process. 2012; 170:19–23
- [6] Dursun T, Soutis C. Recent developments in advanced aircraft aluminium alloys. Mater Des 2014; 56:862–71. <https://doi.org/10.1016/j.matdes.2013.12.002>
- [7] Rohatgi P. Cast aluminium-matrix composites for automotive applications. JOM 1991;43(4):10–5. <https://doi.org/10.1007/BF03220538>
- [8] Rambabu P, Prasad NE, Kutumba Rao VV, Wanhill RJH. Aluminium alloys for aerospace applications. Aerospace materials and material technologies. 2017. p. 29–52. <https://doi.org/10.1007/978-981-10-2143-5>
- [9] Hashim J, Looney L, Hashmi MSJ. Metal matrix composites: production by the stir casting method. J Mater Process Technol 1999;92–93:1–7. [https://doi.org/10.1016/S0924-0136\(99\)00118-1](https://doi.org/10.1016/S0924-0136(99)00118-1)
- [10] Kok M. Production and mechanical properties of Al<sub>2</sub>O<sub>3</sub>particle-reinforced 2024 aluminium alloy composites. J Mater Process Technol 2005;161(3):381–7. <https://doi.org/10.1016/j.jmatprotec.2004.07.068>

- [11] Al-Salihi HA, Mahmood AA, Alalkawi HJ. Mechanical and wear behaviour of AA7075 aluminium matrix composites reinforced by Al<sub>2</sub>O<sub>3</sub> nanoparticles. *Nanocomposites* 2019;5(3):67–73. <https://doi.org/10.1080/20550324.2019.1637576>
- [12] Arivukkarasan S, Dhanalakshmi V, Stalin B, Ravichandran M. Mechanical and tribological behaviour of tungsten carbide reinforced aluminium LM4 matrix composites. *Part. Sci. Technol.* 2018;36(8):967–73. <https://doi.org/10.1080/02726351.2017.1331285>
- [13] Kumar N, Gautam G, Gautam RK, Mohan A, Mohan S. A study on mechanical properties and strengthening mechanisms of AA5052/ZrB<sub>2</sub> in situ composites. *J Eng Mater Technol* 2017;139(1). <https://doi.org/10.1115/1.4034692.011002-1>
- [14] Cheneke S, Karunakar DB. The effect of solution treatment on aging behaviour and mechanical properties of AA2024-TiB<sub>2</sub> composite synthesized by semi-solid casting. *SN Appl. Sci.* 2019; 1:1501. <https://doi.org/10.1007/s42452-019-1531-z>
- [15] Kamrani S, Riedel R, Reihani SMS, Kleebe HJ. Effect of reinforcement volume fraction on the mechanical properties of Al-SiC nanocomposites produced by mechanical alloying and consolidation. *J Compos Mater* 2010;44(3):313–26. <https://doi.org/10.1177/0021998309347570>
- [16] Prasad SV, Asthana R. Aluminium metal-matrix composites for automotive applications: tribological considerations. *Tribol Lett* 2004;17(3):445–53. <https://doi.org/10.1023/B:TRIL.0000044492.91991.f3>.
- [17] Mazahery A, Shabani MO, Salahi E, Rahimpour MR, Tofigh AA, Razavi M. Hardness and tensile strength study on Al<sub>3</sub>Si–B<sub>4</sub>C composites. *Mater Sci Technol* 2012;28(5):634–8. <https://doi.org/10.1179/1743284710y.0000000010>.
- [18] He N, Zhang J, Jin Y, Han F, Zhang X, Chen G. Preparation, microstructures and mechanical properties of in-situ TiB<sub>2</sub>/Al composites by mechanical stirring and subsequent ultrasonic treatment. *Mater Res Express* 2019; 6:116553. <https://doi.org/10.1088/2053-1591/ab471f>.
- [19] Dinaharan I, Murugan N. Optimization of friction stir welding process to maximize tensile strength of AA6061/ZrB<sub>2</sub> in-situ composite butt joints. *Met. Mater. Int.* 2012;18(1):135–42. <https://doi.org/10.1007/s12540-012-0016-z>.

- [20] Mohan A, Gautam G, Kumar N, Mohan S, Gautam RKC. Synthesis and tribological properties of AA5052-base insitu composites. *Compos Interfaces* 2016;23(6): 503–18. <https://doi.org/10.1080/09276440.2016.1155386>.
- [21] Carter CB, Norton MG. *Ceramic materials*. New York: Springer; 2013. <https://doi.org/10.1007/978-1-4614-3523-5>
- [22] Rahaman MN. *Ceramic processing*. CRC Press; 2017.
- [23] Dinaharan I, Balakrishnan M, David Raja Selvam J, Akinlabi ET. Microstructural characterization and tensile behavior of friction stir processed AA6061/Al2Cu cast aluminum matrix composites. *J Alloys Compd* 2019; 781:270–9. <https://doi.org/10.1016/j.jallcom.2018.12.091>.
- [24] Bajakke PA, Malik VR, Deshpande AS. Particulate metal matrix composites and their fabrication via friction stir processing—a review. *Mater. Manuf. Process*. 2019;34(8):833–81. <https://doi.org/10.1080/10426914.2019.1605181>.
- [25] Ma ZY. Friction stir processing technology: a review. *Metall. Mater. Trans. A* 2008;39 A(3):642–58. <https://doi.org/10.1007/s11661-007-9459-0>.
- [26] Kumar A, Pal K, Mula S. Simultaneous improvement of mechanical strength, ductility and corrosion resistance of stir cast Al7075-2% SiC micro- and nanocomposites by friction stir processing. *J Manuf Process* 2017; 30:1–13. <https://doi.org/10.1016/j.jmapro.2017.09.005>.
- [27] Zhao K, Liu Z, Xiao B, Ma Z. Friction stir welding of carbon nanotubes reinforced Al-Cu-Mg alloy composite plates. *J Mater Sci Technol* 2017; 33:1004–8. <https://doi.org/10.1016/j.jmst.2017.01.033>.
- [28] Cavaliere P, Jahantigh F, Shabani A, Sadeghi B. Influence of SiO<sub>2</sub> nanoparticles on the microstructure and mechanical properties of Al matrix nanocomposites fabricated by spark plasma sintering. *Compos. Part B Eng*. 2018;146(January): 60–8. <https://doi.org/10.1016/j.compositesb.2018.03.045>.
- [29] Durowoju MO, Sadiku ER, Diouf S, Shongwe MB, Makena IM, Ramakokovhu MM, et al. Wear and corrosion studies of graphite-aluminum composite reinforced with micro/nano-TiB<sub>2</sub> via spark plasma sintering. *Mater. Sci. Eng. Technol*. 2019;50 (2):126–39. <https://doi.org/10.1002/mawe.201700062>.
- [30] Zhang X, Liang S, Li H, Yang J. Mechanical and optical properties of transparent alumina obtained by rapid vacuum sintering. *Ceram Int* 2017;43(1):420–6. <https://doi.org/10.1016/j.ceramint.2016.09.175>.

- [31] Prashantha Kumar HG, Xavier MA. Encapsulation and microwave hybrid processing of Al 6061–graphene–SiC composites. *Mater. Manuf. Process.* 2018;33 (1):19–25. <https://doi.org/10.1080/10426914.2017.1279320>.
- [32] Asadipannah Z, Rajabi M. Production of Al–ZrB<sub>2</sub> nano-composites by microwave sintering process. *J. Mater. Sci. Mater. Electron.* 2015; 26:6148–56. <https://doi.org/10.1007/s10854-015-3195-9>
- [33] Ashwath P, Xavier MA. Effect of ceramic reinforcements on microwave sintered metal matrix composites. *Mater. Manuf. Process.* 2018;33(1):7–12. <https://doi.org/10.1080/10426914.2016.1244851>
- [34] Narciso J, Molina JM, Rodríguez A, Rodríguez-reinoso F, Louis E. Effects of infiltration pressure on mechanical properties of Al-12Si/graphite composites for piston engines. *Compos Part B Eng* 2016; 91:441–7. <https://doi.org/10.1016/j.compositesb.2016.01.022>.
- [35] Yang W, Zhao Q, Xin L, Qiao J, Zou J, Shao P, et al. Microstructure and mechanical properties of graphene nanoplates reinforced pure Al matrix composites prepared by pressure infiltration method. *J Alloys Compd* 2018;732: 748–58. <https://doi.org/10.1016/j.jallcom.2017.10.283>
- [36] Rohatgi PK, Kim JK, Gupta N, Alaraj S, Daoud A. Compressive characteristics of A356/Fly ash cenosphere composites synthesized by pressure infiltration technique. *Compos Part A Appl Sci Manuf* 2006;37(3):430–7. <https://doi.org/10.1016/j.compositesa.2005.05.047>
- [37] Zhou C, Wu X, Ngai TL, Li L, Ngai S, Chen Z. Al Alloy/Ti<sub>3</sub>SiC<sub>2</sub> composites fabricated by pressure less infiltration with melt-spun Al alloy ribbons. *Ceram Int* 2018;44(6):6026–32. <https://doi.org/10.1016/j.ceramint.2017.12.212>.
- [38] Tao P, Wang Y. Improved thermal conductivity of silicon carbide fibres-reinforced silicon carbide matrix composites by chemical vapor infiltration method. *Ceram Int* 2019;45(2):2207–12. <https://doi.org/10.1016/j.ceramint.2018.10.132>.
- [39] Soltani S, Khosroshahi RA, Mousavian RT, Jiang Z, Boostani A, Brabazon D. Stir casting process for manufacture of Al – SiC composites. *Rare Met Mater Eng* 2017; 36(7):581–90. <https://doi.org/10.1007/s12598-015-0565-7>.
- [40] Kandpal BC, Kumar J, Singh H. Manufacturing and technological challenges in stir casting of metal matrix composites- a review. *Mater. Today Proc.* 2018;5(1): 5–10. <https://doi.org/10.1016/j.matpr.2017.11.046>.

- [41] Pazhouhanfar Y, Eghbali B. Microstructural characterization and mechanical properties of TiB<sub>2</sub> reinforced Al6061 matrix composites produced using stir casting process. *Mater. Sci. Eng. A* 2018; 710:172–80. <https://doi.org/10.1016/j.msea.2017.10.087>
- [42] Lu Y, Li J, Yang J, Li X. The fabrication and properties of the squeeze-cast TiN/Al composites. *Mater. Manuf. Process.* 2016;31(10):1306–10. <https://doi.org/10.1080/10426914.2015.1070417>
- [43] Gurusamy P, Prabu SB, Paskaramoorthy R. Influence of processing temperatures on mechanical properties and microstructure of squeeze cast aluminum alloy composites. *Mater. Manuf. Process.* 2015;30(3):367–73. <https://doi.org/10.1080/10426914.2014.973587>
- [44] Huang X, Liu C, Lv X, Liu G, Li F. Aluminum alloy pistons reinforced with SiC fabricated by centrifugal casting. *J Mater Process Technol* 2011;211(9):1540–6. <https://doi.org/10.1016/j.jmatprotec.2011.04.006>.
- [45] Gangil N, Siddiquee AN, Maheshwari S. Aluminium based in-situ composite fabrication through friction stir processing: a review. *J Alloys Compd* 2017;715: 91–104. <https://doi.org/10.1016/j.jallcom.2017.04.309>.
- [46] Ujah CO, Popoola API, Popoola OM, Aigbodion VS. Enhanced Tribology, Thermal and Electrical Properties of Al-CNT Composite Processed via Spark Plasma Sintering for Transmission Conductor. *J Mater Sci* 2019; 54:14064–73. <https://doi.org/10.1007/s10853-019-03894-x>.
- [47] Sun M, Bai Y, Li M, Fan S, Cheng L. Structural Design of Laminated B<sub>4</sub>C/TiC Composite Fabricated by Reactive Melt Infiltration. *J Alloys Compd* 2018;765: 913–20. <https://doi.org/10.1016/j.jallcom.2018.06.271>
- [48] Raei M, Panjepour M, Meratian M. Effect of stirring speed and time on microstructure and mechanical properties of cast Al–Ti–Zr–B<sub>4</sub>C composite produced by stir casting. *Russ. J. Non-Ferrous Met.* 2016;57(4):347–60. <https://doi.org/10.3103/S1067821216040088>
- [49] Hajjari E, Divandari M, Arabi H. Effect of applied pressure and nickel coating on microstructural development in continuous carbon fibre-reinforced aluminium composites fabricated by squeeze casting. *Mater. Manuf. Process.* 2011;26(4): 599–603. <https://doi.org/10.1080/10426910903447311>

[50] Adelakin TK, Su´arez OM. Study of boride-reinforced aluminium matrix composites produced via centrifugal casting. Mater. Manuf. Process. 2011;26(2):338–45. <https://doi.org/10.1080/10426910903124829>.

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