

**Determination of Mechanical properties of TiB_2
reinforced Ti-SiC produced by
Powder metallurgy.**

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

By

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SATHYABAMA

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

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **HARISH. M (Reg. No. 39260007)**, **KARTHICK. B (Reg. No. 39260011)**, who carried out the Project entitled **"DETERMINATION OF MECHANICAL PROPERTIES OF TiB₂ REINFORCED Ti-SiC PRODUCED BY POWDER METALLURGY."** under our supervision from June 2022 to April 2023.

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ABSTRACT

In this study, the mechanical properties and the microstructural behavior of Titanium diboride (TiB_2) of Ti-SiC- TiB_2 based metal matrix composite (MMC) were investigated. Throughout the investigation the percentage of Silicon carbide (SiC) is maintained at 10% and for Titanium diboride, the sample percentages are 2, 5, and 10% and the remaining percentages are fulfilled by Titanium (88, 85 and 80%) by the application of compaction pressure of 35 MPa the samples were made by powder metallurgy process. The surface topography and structure of the materials are obtained using SEM-EDS and XRD analysis. Further, the samples made through powder metallurgy were subjected to destructive tests like microhardness and UTM to determine the mechanical properties of the fabricated hybrid composite material. Titanium matrix composites (TMCs) exhibit superior specific strength and stiffness when compared with steel and nickel-based materials. High-temperature TMCs can save weight in the propulsion sections of jet engines by up to 50% as compared to monolithic superalloys while maintaining the same stiffness and strength. The unique properties of Titanium matrix composite (TMC) have thrust them to the forefront of significant research and development programs across the globe, whether continuous fibers or discontinuous particles are employed as reinforcement. TMCs have become the most studied and desirable material systems as a whole yet the literature lacks useful details about their characteristics, production methods, and design. This report discusses significant studies that helped enhance TMCs material systems. Additionally, it offers thorough information on typical reinforcements, production procedures, and reviews.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS AND ABBREVIATIONS	DESCRIPTION
Ti	Titanium
SiC	Silicon carbide
TiB ₂	Titanium diboride
PM	Powder metallurgy
MMC	Metal matrix composite
°C	Degree celsius
GPa	Giga pascal
MPa	Mega pascal
g	Grams
cm	Centi meter
K	Kelvin
%	Percentage
UTS	Ultimate tensile strength
YS	Yield strength
HV	Vickers hardness

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO COMPOSITE MATERIAL

When two materials are combined that have various physical and chemical properties, a composite material is created. It is possible to combine them to produce a substance that has a particular desired property, such as increasing strength, weight, or electrical resistance. Strength and stiffness can both be enhanced by them. Due to their versatility and ability to enhance the qualities of the underlying material, they are preferred to conventional materials.

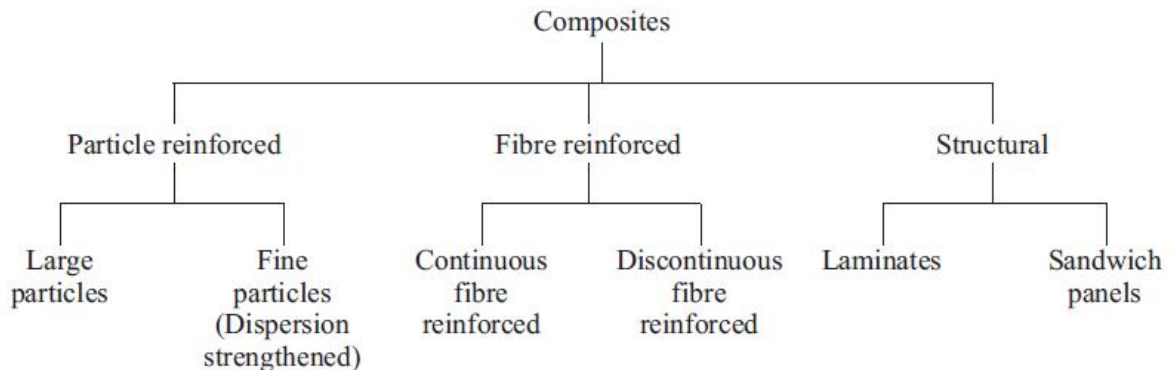


Fig 1.1 Classification of composite material

1.2 ADVANTAGES OF COMPOSITE MATERIAL

1. Outstanding ratio of strength to weight can be accomplished by composite materials
2. Composite exhibits excellent corrosion resistance, thermal resistance, and chemical attacks.
3. Composites are easier to produce.
4. No need for any high-level maintenance.
5. Composites are extremely durable and long-lasting materials.

6. When compared to most woods and materials, composites are light in weight.

1.3 DISADVANTAGES OF COMPOSITE MATERIAL

1. Composite materials can easily be damaged. Because it is more brittle in nature than wrought materials.
2. Cost of raw materials and fabrication is high.
3. May be weaker in the transverse property.
4. Reuse and disposal may be difficult.

1.4 TITANIUM-BASED METAL MATRIX COMPOSITES (TMCS)

Although titanium alloys are less dense than steels and stronger than alloys based on aluminum, they nevertheless have far lower strength than high-strength steels. Consequently, improving titanium alloy strength is the main goal. Titanium matrix composites (TMCs), which ought to possess an excellent elastic modulus, extreme-temperature endurance, resistance to wear, isotropic property, and formability, are one of the most essential metal matrix composites (MMCs). Designing composite metal matrix materials has as its goal fusing the best qualities of metals and ceramics. The mechanical properties of the material produced by the inclusion of high-strength, high-modulus refractory particles to a ductile metal matrix fall somewhere between those of the matrix alloy and the ceramic reinforcement. Metal matrix composites, or MMCs, are metals reinforced with additional metal, ceramic, or organic materials. These MMCs are created by distributing the reinforcements throughout the metal matrix. Reinforcements are used to improve the base metal's qualities, such as strength, stiffness, conductivity, etc. Both silicon carbide (SiC) and titanium diboride (TiB₂) were used as reinforcements throughout the fabrication process. Powder metallurgy is a manufacturing method that uses intense pressure on powdered metals and alloys in a hard die to create precise and extremely accurate objects. As a result of the development and application of technological developments, powder metallurgy has developed into an essential method for the production of bearings, gears, and a

variety of structural components. The precision and effectiveness of powder metallurgy depend on the sintering process, which requires heating components and exerting pressure to unite the powder particles. The bonds between the powdered particles are joined during sintering, which takes place at a temperature that is just below the parent metal's melting point.

1.5 ADVANTAGES OF USAGE OF TITANIUM AS MAIN METAL MATRIX

Due to its special mix of qualities that make it the ideal material for use in the production of aircraft components, titanium has a variety of uses in the aerospace sector. The following are some of the most significant uses for titanium in the aerospace industry. Titanium has a high-temperature resistance and strength-to-weight ratio, which makes it the perfect material to use in the construction of aircraft engine structural components for aircraft. They include wings, fuselage frames, engine mounts, and landing gear. Since titanium has a high strength-to-weight ratio and can withstand high loads, strains, lighter and more efficient aircraft can be created.

Titanium is frequently utilized in the construction of engine parts like compressor blades, turbine blades, and rotors. Because of its high strength-to-weight ratio and minimal thermal expansion, Titanium is the perfect material for these applications because these components must tolerate high temperatures and stresses.

Heat Shields: Titanium is also utilized in the construction of heat shields, which insulate aircraft from the high temperatures created during re-entry into the atmosphere. Titanium is a perfect material for this purpose because of its special qualities that enable it to tolerate high temperatures and thermal shock. Titanium is widely used in the production of fasteners like bolts, screws, and nuts. When great strength and corrosion resistance are necessary, these components are used in demanding applications.

1.6 ADVANTAGES OF USING SiC AND TiB₂ AS REINFORCEMENTS

High thermal conductivity: SiC acts as a great material for higher temperature applications due to its thermal conductivity, which is 3-5 times higher than that of silicon.

High power handling capacity: Silicon carbide devices can manage far higher power densities than silicon-based devices, which makes them well-suited for power electronics applications like electric vehicles

Wide bandgap: SiC can operate at higher temperatures and voltages without breaking down because it has a wider bandgap than silicon. This makes it an ideal material for high-performance devices that need to operate in harsh environments.

SiC is a material with a high degree of hardness and stiffness, making it ideal for high-stress applications like cutting tools.

High melting point: TiB₂ is suitable for use in applications that require high temperatures due to its elevated melting point of 2980 °C.

Hardness: TiB₂ has a high hardness of 30 GPa, which is similar to that of the diamond. This feature makes it suitable in applications where wear resistance is required, such as cutting tools.

Low density: TiB₂ is lightweight and ideal for use in aeronautical applications because of its lower density of 4.52 g/cm³.

High electrical conductivity: TiB₂ is an excellent material for electrical contacts and resistors because of its high electrical conductivity.

TiB₂ has a high resistance to oxidation and corrosion, making it useful in applications where exposure to harsh environments is anticipated.

CHAPTER-2

LITERATURE REVIEW

O.N. Dogan et al. investigated the put-on of titanium carbide-strengthened metallic matrix composites and concluded that With increasing hardness, the amount of wear loss of the TiC particle reinforced composites reduces in each of the three macroscopic rough put-on environments used in this investigation. Large TiC particles and multidirectional abrasion settings, such as pin-on drum tests, have provided higher protection for the softer matrices at low to medium hardness in situations of extreme stress. Common benefits in dress code are typically only awarded to composites with the highest achievable hardness value.

V.Sivananth et al. studied the comparison of fatigue and the effective conduct of titanium carbide-strengthened metallic matrix composites in conclusion, the XRD & SEM analyses stated that large Al_3Ti blocks and Al_4C_3 blocks formed at some point in the reaction between Al permit and titanium carbide at 750°C , when the reaction was once steady, the intermetallic stages had decreased. This is used because an elevated structure formed at this temperature in the vicinity of TiC particles is responsible for this decrease. Due to the influence of the matrix's region, the composite's reinforcement-free matrix region serves as the initial site of fracture. The cleavage failure mechanism is typically the cause of the low energy in the strengthened alloy. The influence strength is decreased by the unreinforced alloy, which permits cracks to spread quickly in more than one direction in the absence of any obstruction.

Priyaranjan Samal et al. investigated the fabrication and mechanical houses of titanium carbide-strengthened aluminum composites and concluded Regardless of the weight percentage, the morphological information revealed the existence of TiC with an even distribution throughout the composites. The composites once obtained the majority of 32% and 78% extended in micro-hardness and residual tensile energy, respectively. By the backside pouring stir casting technique, it was previously

observed that nano aluminum particles may significantly increase in tensile and yield strength when reinforced with an aluminum matrix.

K.Ravikumar et al. studied the microstructural traits and mechanical conduct of aluminium matrix composites reinforced. With titanium carbide, It was determined that the XRD analysis shows that TiC and aluminum are the important components present in composites, showing that they are free of impurities. It was also determined that TiC's higher density made the composite's density more significant than the base alloy. Combining TiC and extension increased the composite's density, hardness, and tensile strength while decreasing its elongation and influencing electricity. The Orowan and Hall-Petch strengthening mechanisms, as well as the contact between the reinforcement and matrix, will further boost the composites' hardness. The processing method and post-processing warm-up procedure have an impact on the composites' hardness.

The high-strain-rate response of titanium matrix composites strengthened with the titanium carbide particles at expanded temperature is studied through the usage of SHTB with fast contact heating system. The modified J-C mannequin can be used to exactly predict the float stress for the TiC/Ti composite and can be employed to analyze the warm deformation conduct in the course of the steel forming procedure. Jin-seon Kim et al. investigated the fretting put-on traits of Titanium-based metal matrix composites bolstered through Titanium carbide and Titanium boride particulates and concluded, the fretting regimes had been categorized and then they put on the mechanism used to be investigated underneath the gross slip and the partial slip regimes. The oxide layer happened for the duration of the put-on test, and the friction and put-on charge grew to become secure the put-on charge dropped. Some other tests used to be carried out to inspect the impact of the oxide layer use of pre-formed oxide layer on the TMCs. The wear resistance of the pre-oxidized samples was once increased.

Lirong Tong et al. investigated and concluded TiC nano-powders can be made using Ti and CH₄ as the starting materials through thermal plasma, and it has been demonstrated that this method of making TiC powder is thermodynamically feasible. The common size of the TiC powder particles is less than 100 nm. TiC nanopowders

made through synthetic means have a non-stoichiometric composition. The results of the experiments showed that adding more CH₄ to the feeding is especially beneficial for producing titanium carbide that is almost stoichiometric. Experimental findings showed that the entraining energy must be as high as attainable, the feeding rate must be less than 5 g/min, and the molar must be used to prevent Ti and C from entering the product powder.

Sánchez et al. studied and rounded off, with mechanical capabilities comparable to the best grades of traditional hard metals ($HV_{10} \approx 19$ GPa and $K_{ICSR} \approx 9 \text{ MPa} \cdot \sqrt{\text{m}}$), TiB₂-based cermets are extremely hard materials. These findings represent a substantial advancement above the TiB₂ composites created up to this point. The increase in fracture toughness found in these materials is caused by the metallic binder phase's plastic behavior during fracture, as explained in this article. Additionally, it has been demonstrated that metastable austenitic binder phases contribute to a further rise in fracture toughness via a mechanism known as transformation toughening. Additionally, to prevent brittle intergranular phases that result in incredibly brittle materials, strict chemical composition control of the metallic binder is essential. On the cost of TiC combustion, preliminary experiments have been done. It was once revealed in one series of these research that adding 10% Titanium carbide as a diluent causes the combustion way to change from a steady to a quasi-steady (oscillating) one. The combustion temperature, T_c , was measured, and the results showed that adding 10% titanium carbide as a diluent caused T_c to drop from 2720 to 2518 K.

By laser cladding with 5, 10, 15, and 20-weight percent CNTs, TiC-bolstered Ti matrix composite layers have been created. The coatings were composed of a matrix of alpha-titanium phases and the TiC reinforcing segment in the form of tiny dendrites, indicating that TiC had previously been created using carbon nanotubes to enhance titanium's in-situ reaction during laser irradiation. Because of the titanium carbide reinforcements, the composite layers exhibit exceptional hardness and excellent resilience. TiC particles are appropriately used as a reinforcing phase in composite materials because of their superior mechanical qualities, distinctive electrical characteristics, and high-temperature resistance.

Sodium chloride was used as an additive during the successful synthesis of TiC nanopowders using the SHS (Self-propagating high-temperature synthesis) technique. The combustion process of sodium chloride did not form any intermediary phases, and sodium chloride was found to be innocuous to the machine. Additionally, it has been proven that the protective NaCl media that was present around the initial carbide crystals helped shape the TiC nanopowders. $m = 0.4$ (or roughly 30 weight percent) was the ideal additive extent for obtaining TiC nanoparticles in the past.

Due to Ti and C's higher affinity, titanium carbide tends to form before Ti-Si compounds. After being launched, Si interacts with Ti to produce the intermetallic compound Ti_5Si_3 . Additionally, TiC's melting point is higher than Ti_5Si_3 's. As will be demonstrated later by the HRTEM research, Ti_5Si_3 likes to nucleate and grow on the early-fashioned TiC in this instance.

To improve the wear resistance of Ti_6Al_4V alloys, titanium matrix composite coatings with TiB and TiC reinforcement was developed. The coatings are predominantly made of TiC and TiB particles that have been uniformly disseminated in a (Ti) matrix with interdendritic eutectics and coarse dominating cell dendrites. Additionally, the volume fraction of titanium carbide increased with the addition of Y_2O_3 . In contrast to the coating with a dendritic structure, the coating with distributed good TiC particles displayed excessive hardness and proper put-on characteristics. Furthermore, the coating became weaker as a result of a dendritic boom of titanium carbide particles. The findings demonstrated that TiC, TiB_2 , and matrix -Ti were frequently present in the coatings. If enough CeO_2 is added, the "herringbone" cracks may be improved and enhance the floor quality of the coatings. The microhardness of the composite coating (600 HV0.2) is almost twice that of the Ti_6Al_4V substrate (340 HV0.2), thanks to the titanium carbide particles' nanoindentation hardness of roughly 22 GPa. The hardness of the Ti compact was only marginally affected by the sintering temperature. Due to a larger conversion of Ti to $TiCx$, it was once discovered that the hardness of Ti-5CNT compacts increased with increasing sintering temperature.

The following explanations are given for the difference between the excessive temperature placed on the titanium carbide coatings' mechanism and that of the titanium substrate. Under the microstructure observation and hardness comparison,

the TiC coatings made with CNTs can reinforce the TiC section. Due to the dispersion hardening effect of TiC and TiB, the coating's hardness (752.6 HV0.1) is significantly more suited than the substrate. The intermetallic compound $\text{Al}_{12}\text{Mg}_{17}$ and the TiC ceramic section both enhance the micro-hardness. Additionally, the composite coating's hardness is significantly impacted by the substantial response strengthening of Al in Mg. As the new floor emerges during the milling process, the particle grain size or crystal grain size decreases as the outside portions grow. As a result, grinding powders offer more entertainment and free energy outside. The interfacial reaction between titanium carbide and aluminum was better during sintering at a temperature of 600°C. The superior interfacial response of the reinforcement particles and the matrix was demonstrated by SEM, EDX, and microstructure. The addition of titanium carbide will increase the positive stress necessary for deformation in the composite metal, which will also result in an increase in the stress ratio values for a particular element ratio and lubrication condition. With an increase in TiC particles, the sintered density of the composites falls. Cu-5Gr and Cu-5Gr-TiC have maximum and minimum relative densities of 83.25% and 74.01%, respectively. At higher TiC concentrations, the impediment to compaction causes an increase in porosity and, as a result, low density.

CHAPTER-3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

1. To prepare Ti -10% SiC- 2,5 and 10% TiB₂ composite samples using the powder metallurgy method.
2. To evaluate the surface topography of the samples using scanning electron microscopy.
3. To evaluate their structural arrangement using XRD analysis and SEM-EDS.
4. To obtain the mechanical properties of the samples using a microhardness test, scratch test, tensile test, and impact test.

CHAPTER- 4

METHODOLOGY AND MATERIALS

4.1 METHODOLOGY:

4.1.1 Powder metallurgy;

When powdered metals and alloys are pressed into a stiff die under intense pressure, a manufacturing technique known as powder metallurgy produces parts that are exact and extremely accurate. As a result of the design and use of technological developments, powder metallurgy has developed into a crucial process for the production of bushings, bearings, gears, and a variety of structural components. The accuracy and effectiveness of powder metallurgy depend on the sintering process, which includes heating elements to fuse the powder particles. The bonds that connect the powdered particles solidify during the process of sintering, which takes place at a temperature just below the main metal's melting point. Powder metallurgy is a traditional, distinctive method for forming and producing patterns from ferrous and non-ferrous metals. Powder metallurgy has been used for making household items and tools for thousands of years. It began as a method for producing in large quantities goods and components in the midst of the first industrial revolution. Up to the early 20th century, the procedure was sporadically used, but it wasn't thought of as a useful production method. Due to the invention of electricity and other technological breakthroughs, powder metallurgy has become an extremely efficient and profitable technology for producing parts with precise tolerances and minimum waste.

The powder metallurgy process consists of the following four fundamental steps: powder preparation, mixing and blending, compacting, and sintering. Over the years, many different goods have been created using these procedures. Like any production process, powder metallurgy can be customized to meet the needs of certain items. The evolution of technology advancements and engineering criteria has given rise to many ways and procedures. Conventional, injection molding, isostatic pressing, and

the most recent development in metal additive manufacturing are four of the variations.

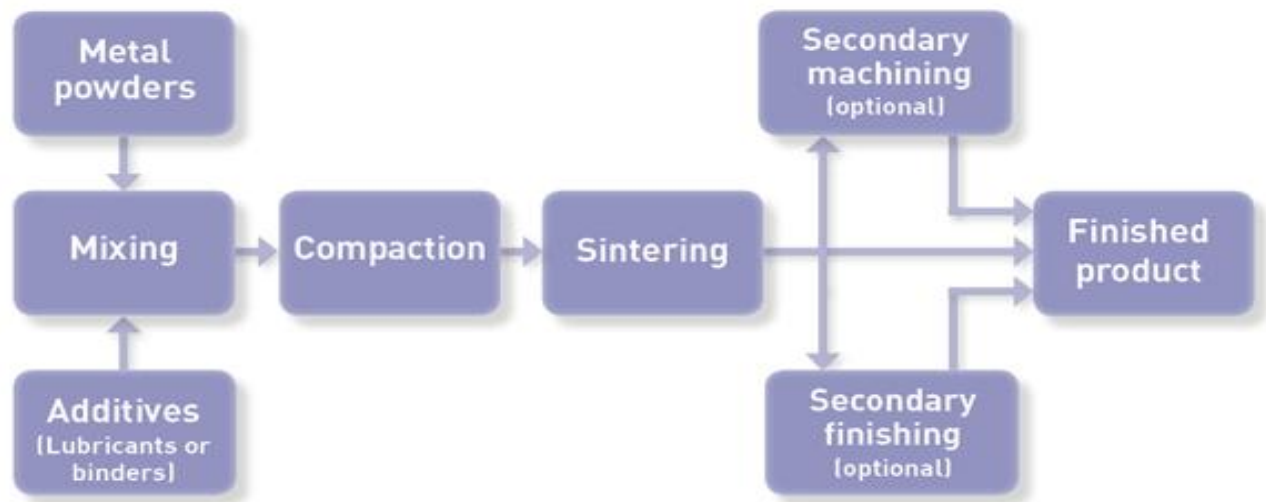


Fig.4.1 powder metallurgy

4.2 BASIC STEPS OF POWDER METALLURGY:

4.2.1 powder preparation:

The characteristics of the things created by powder metallurgy depend on the qualities and features of the powder. One technique for producing powder for use in powder metallurgy is melt atomization. The process involves breaking up liquid metal into small droplets, which subsequently cool and solidify into tiny particles. Chemical reduction, electrolytic deposition, and atomization are other processes for producing powder in addition to grinding and thermal breakdown. Regardless of the technique used, all metals and alloys can be broken down into a powder. Before being blended and combined, the powder is evaluated and tested to make sure it is appropriate for

the powder metallurgy process. Flow rate, density, compressibility, and strength are among the factors taken into consideration.



Fig 4.2 powder preparation

4.2.2 Mixing and Blending:

In the powder metallurgy (PM) process, which involves creating metal parts or components using powders as the initial material, mixing and blending are essential phases. Different metal powders, alloying components, and other additives are commonly combined during the mixing and blending process in PM to produce a homogeneous mixture that is prepared for further processing processes like compaction and sintering.

The mixing and blending process in PM serves several important purposes:

Homogenization: The primary objective of mixing and blending is to achieve a uniform distribution of metal powders and other additives, ensuring that the resulting mixture has a consistent composition throughout. This helps to avoid localized variations in composition, which could lead to inconsistent properties in the final product.

Alloying: Powder metallurgy is often used to produce alloys with specific compositions and properties. Mixing and blending are used to thoroughly mix the different metal powders and alloying elements in precise proportions to achieve the desired alloy composition.

Dispersion: Additives such as lubricants, binders, and solid lubricants are commonly used in PM to facilitate the compaction and sintering processes. Mixing and blending ensure that these additives are evenly dispersed throughout the metal powders, allowing them to perform their intended functions effectively.

Particle size control: The size of the metal powders used in PM can affect the properties of the finished outcome product. Mixing and blending could be helpful to achieve the desired particle size distribution by combining powders of different sizes in appropriate proportions.

The mixing and blending process in PM can be carried out using various methods, depending on the scale of production, desired properties of the final product, and available equipment. Some common methods include:

Dry mixing: Metal powders and other additives are mechanically mixed together in a dry state using equipment such as tumbling mixers, V-blenders, or ribbon blenders. Dry mixing is typically used for small-scale production when the powders are compatible and do not react with each other.

Wet mixing: Metal powders and additives are mixed together in a liquid medium, such as water or a solvent, to form a slurry. The slurry is then dried to obtain a homogeneous powder mixture. Wet mixing is used when powders are not compatible or when a finer level of mixing is required.

Mechanical alloying: This method involves milling metal powders and alloying elements together in a high-energy ball mill or attritor mill, resulting in the formation of alloyed powders. Mechanical alloying is used to achieve a high level of alloying and is commonly employed for producing advanced materials with unique properties.

Spray drying: This method involves dispersing metal powders and other additives in a liquid medium, then spraying the mixture into a drying chamber, where

the liquid evaporates, leaving behind dry powder particles. Spray drying is commonly used for producing homogeneous mixtures of fine powders.

In summary, the mixing and blending process in powder metallurgy is a crucial step in achieving a uniform distribution of metal powders, alloying elements, and additives, and plays a significant role in determining the composition and properties of the final product. Various methods can be used depending on the specific requirements of the production process and the desired properties of the final product compacting

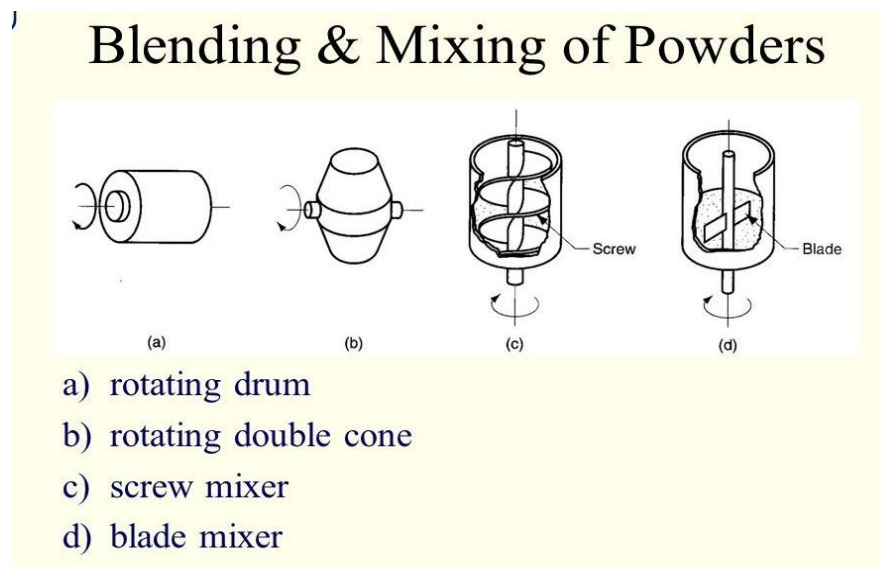


Fig 4.3 Mixing and blending of powders

4.2.3 Compacting:

Compaction is a critical step in the powder metallurgy (PM) process, which involves the consolidation of metal powders into a desired shape or component using mechanical force. It is the first step in transforming loose, fine metal powders into a solid structure before further processing through sintering or other thermal treatments.

The compaction process typically involves the following steps:

Powder Selection: Metal powders are selected based on the desired properties of the final component, such as composition, size, and shape. Powder characteristics, such as particle size distribution, shape, and surface area, have a significant impact on the compaction behavior and the quality of the final product.

Die Filling: The selected powders are carefully loaded into a die, which is a tool that determines the final shape and size of the component. The powders are distributed uniformly and compacted to achieve the desired density and shape.

Compaction: Mechanical force is applied to the powders in the die to compress them into a solid structure. The force can be applied using various methods, including uniaxial compaction (pressure applied in one direction), isostatic compaction (uniform pressure applied from all directions), or cold isostatic pressing (pressure applied using a fluid medium).

Ejection: Once the powders are compacted to the desired shape and density, the component is ejected from the die. This may be done by applying additional force or by using ejector pins.

Green Part Formation: The compacted component, also known as a "green part," is still relatively fragile and requires careful handling to avoid damage. Green parts are generally porous and may have some residual stresses due to the compaction process.

Post-Compaction Operations: In some cases, additional operations may be performed on the green part, such as sizing, coining (to improve surface finish), or machining to achieve the final shape and dimensions.

The characteristics of the powders, the compaction parameters (such as pressure, temperature, and rate of compaction), and the die design all have an impact on the quality of the compacted component. The finished sintered component must be compacted properly to provide the correct density, form, and mechanical qualities.

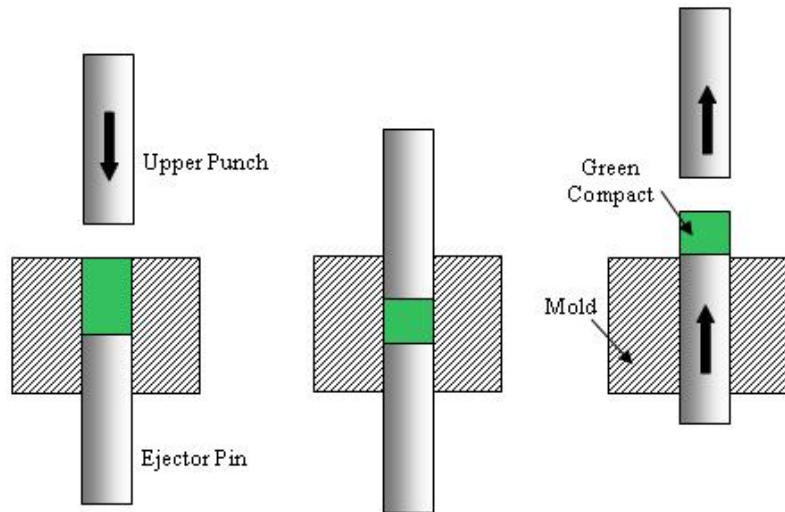


Fig 4.4 compaction process

4.2.4 Sintering:

Sintering is a critical process in powder metallurgy, which is a manufacturing technique used to produce components from metal powders. Powder metallurgy involves the consolidation of metal powders into a solid object through the application of heat and pressure, without melting the powder.

Sintering: The green compact is then subjected to heat in a controlled environment, typically in a furnace. During sintering, the metal powders undergo several important changes. At lower temperatures, the powders begin to bond together through a process called solid-state diffusion. This is facilitated by the presence of elevated temperatures and the application of pressure, allowing the metal powders to rearrange and fuse together.

Densification: The metal powders continue to bond and reorganize as the sintering process progresses, reducing porosity and increasing component density. The final mechanical qualities, like strength and hardness, are developed as a result.

Grain growth: During sintering, the metal powders may also undergo grain growth, where the individual powder particles grow in size. This can result in changes in the microstructure and mechanical properties of the final component.

Cooling and final treatment: Once the sintering process is complete, the component is cooled down to room temperature. Depending on the requirements of the final component, additional treatments such as heat treatment, machining, and surface finishing may be applied to achieve the desired properties and dimensions.

Sintering in powder metallurgy is a versatile and widely used process that allows for the production of complex shapes, high-strength materials, and components with controlled porosity. It is commonly used in various industries, including automotive, aerospace, energy, and healthcare, to manufacture a wide range of components such as gears, bearings, filters, cutting tools, and structural parts.

4.2.5 Secondary finishing:

Secondary finishing, also known as secondary operations or post-processing, refers to additional steps or treatments applied to powder metallurgy (PM) components after they have been formed using PM techniques. In the process of making solid components with the necessary qualities, metal powders are compressed and sintered in powder metallurgy. Secondary finishing is performed to further enhance the properties, performance, and appearance of the PM components, and may involve various techniques such as machining, heat treatment, coating, and surface treatment.

Here are some common secondary finishing processes in powder metallurgy:

Machining: In order to attain precise dimensions, tolerances, or surface finishes, PM components may need to be machined. To remove extra material, make holes or features, or achieve the necessary surface roughness, PM components may undergo machining processes such as turning, milling, drilling, and grinding.

Heat treatment: Heat treatment is a common secondary finishing process used in PM to improve the mechanical properties of the components. Heat treatment techniques such as sintering, annealing, hardening, and tempering can be applied to PM components to enhance their strength, hardness, toughness, and dimensional stability.

Coating: To provide extra qualities to a PM component, such as better wear resistance, corrosion resistance, or thermal insulation, a layer of material is coated on the surface of the component. Electroplating, electroless plating, thermal spraying, and chemical vapor deposition are some of the coating techniques utilized in PM.

Surface treatment: Surface treatment techniques such as polishing, deburring, and shot peening may be used to improve the surface quality, appearance, and functional properties of PM components. Polishing can provide a smoother surface finish, deburring can remove sharp edges or burrs, and shot peening can induce compressive stresses in the surface layer to improve fatigue resistance.

Secondary pressing: Secondary pressing is a process where additional compaction is applied to PM components after sintering to further increase their density, strength, and dimensional accuracy. This can be done using hydraulic or mechanical presses to achieve a higher level of compaction and reduce porosity in the components.

Infiltration: Infiltration is a process where a low-melting-point material, such as a metal or a polymer, is melted and allowed to infiltrate the porous structure of a PM component. This can improve the density, strength, and toughness of the component, as well as provide additional properties such as sealing or electrical conductivity.

Overall, secondary finishing processes in powder metallurgy are essential for achieving the desired properties, performance, and appearance of PM components, and are often tailored to the specific requirements of the application.

4.3 ADVANTAGES OF POWDER METALLURGY:

1. Desired shapes and dimensions can be easily obtained.
2. Do not require any further finishing.
3. Wastage of raw material is at the very least possible.
4. It gives the characteristics of the manufactured parts like porosity and self-lubrication.
5. Powder metallurgy process is environmental friendliness.

4.4 LIMITATIONS OF POWDER METALLURGY:

1. When compared to stir casting or machined parts, mechanical properties obtained by powder metallurgy could be low.
2. Production of metallic powder is expensive.
3. Raw material cost is high
4. Powder metallurgy cannot be performed in large production.

4.5 APPLICATION- JET ENGINE TURBINE DISC:

Extreme temperatures and a range of pressures must be withstood by aircraft turbines. Engine fans, compressors, and turbine blades are all connected to the turbine disc, which is its central component. Turbine discs are produced using high-temperature alloys that adhere to the necessary specifications and grades. In order to attain the best performance, turbine discs are machined and finished.

Turbine discs are produced using powder metallurgy processes and atomized powders. Since it's necessary to prevent the entrance of undesirable particles or pollutants, the process is challenging and complicated.



Fig 4.5 jet engine turbine disc

4.6 MATERIALS

4.6.1 Titanium powder

Titanium particles make up titanium powder, a fine metallic powder. A transition metal called titanium is known for its great strength, lightweight, and resistance to corrosion. The small particle size of titanium, which can be as small as a few nanometers or as large as several hundred micrometers, gives it certain special qualities when it is treated in powder form. For many years, titanium powder has been used as an alloying element in a variety of applications. Using it makes it feasible to machine intricate pieces made of wrought billet without experiencing any material loss of all.

The Kroll method is the conventional titanium extraction procedure. Alloying, hot isostatic pressing and other sub-processes are part of this technology, which demands temperatures of up to 1040°C. The production of pre-alloyed titanium powder requires the use of additional techniques after that. The hydride-dihydride

process, cold compaction, vacuum hot pressing, final vacuum annealing, plasma rotating electrode process, titanium gas atomization process, and plasma atomization must all be applied to the material in order to remove impurities. A variety of metal consolidation techniques must be used to create the finished product. A reliable, affordable process for producing big numbers of small-sized metals is powder injection molding, often known as metal injection molding. The direct powder rolling procedure is another one that is used to make plates and sheets. The laser-designed net shaping technology is used to fabricate, improve, and repair metal components quickly.

Titanium powders require hot isostatic pressing, which is carried out under high pressure and temperature, to be consolidated to their theoretical maximum densities. Finally, spark plasma sintering, also known as electric current-aided sintering, is used to create the final product, producing titanium powder with excellent mechanical properties and good grain size, without any undesirable grain development. One of the most recent developments in metal fabrication is the use of titanium powder to print three-dimensional vehicle components. Through the use of 3D printing, it is possible to produce various parts and components for car and aerospace engine frames.

4.6.1.1 Properties of Titanium powder (Ti):

High Strength-to-Weight Ratio: Titanium powder is one of the strongest and lightest metallic powders on the market thanks to its high strength-to-weight ratio. Due to this characteristic, it is perfect for use in the aerospace and automotive sectors and other fields where high strength and low weight are priorities.

Corrosion Resistance: Titanium powder is highly resistant to corrosion, even in harsh environments such as saltwater or acidic conditions. This property makes it suitable for applications where exposure to corrosive substances is common, such as in marine and chemical processing industries.

High Melting Point: Titanium's high melting point of 1668°C (3034°F) allows it to survive high temperatures without losing its mechanical qualities, making titanium powder resistant to them. Because of this, it can be used in high-temperature applications like gas turbines and aerospace engines.

Biocompatibility: Titanium powder is biocompatible, meaning it is not toxic and does not cause adverse reactions in living tissues. This property makes it suitable for medical and dental applications, such as implants, prosthetics, and surgical instruments.

Excellent Thermal and Electrical Conductivity: In applications where heat transfer or electrical conductivity is essential, such as in heat exchangers, electrical connectors, and electronic components, titanium powder is ideal due to its high thermal and electrical conductivity.

Reactivity: Titanium powder is highly reactive and can ignite or react violently with certain substances, such as oxygen, nitrogen, and chlorine, at high temperatures. Proper handling and storage precautions should be taken to prevent accidents.

Sensitive to Contamination: Titanium powder is sensitive to contamination from impurities, such as oxygen, nitrogen, and carbon. Contamination can affect its properties and performance, so proper handling and storage in controlled environments are essential to maintain its purity.

Oxidation: High temperatures can cause titanium powder to oxidise and produce titanium oxide, which can change the material's characteristics. When processing and handling, appropriate safety measures should be followed to avoid oxidation.

These are some of the key properties of titanium powder. The specific properties may vary depending on the manufacturing process, particle size, and surface treatment of the titanium powder. Metal injection molding and powder metallurgy both continue to use titanium powder extensively. Due to its special combination of

qualities, titanium powder is utilized in a wide range of applications, including those in the automotive, aerospace, medical, and industrial sectors.



Fig 4.6 Titanium powder

4.6.2 Silicon Carbide Powder:

The chemical symbol for silicon carbide, a crystalline solid used in industry, is SiC. It functions as a ceramic and a semiconductor and is frequently referred to as carborundum. A wonderfully rare mineral called moissanite naturally contains silica. They resemble colorless, translucent pure silicon carbide crystals. Depending on the quantity of contaminant injected, such as nitrogen or aluminum, silicon carbide crystals take on a green or blue color. Although SiC's combination of ceramic and semiconductor properties makes it suitable for the manufacturing of rapid, high-voltage, and high-temperature devices, its use is mostly driven by its hardness and strength.

4.6.2.1 Properties of silicon carbide powder:

High Melting Point: The silicon carbide material is suited for high-temperature operations such as those used in electrical heating systems and other elevated-temperature industrial processes due to its extraordinarily high melting temperature of around 2700°C.

Hardness: Silicon carbide is among the hardest substances ever discovered, with a hardness that is comparable to diamond. This makes it very durable and wear-resistant, making it suitable in applications like tools for cutting, grinding wheels, and armor materials where robustness and resistance to wear are important.

Silicon carbide has good thermal conduction, which enables it to quickly release heat. Due to this characteristic, it can be used in applications requiring high temperatures such as high-temperature sensors, electrical equipment, and semiconductor heat sinks.

broad Bandgap: The silicon carbide material has a broad bandgap, allowing it to operate at high volts and heat devoid of thermal instability or breakdown. This makes it perfect for high-temperature, high-power electrical devices like high-power switches and sensors for temperature.

Silicon carbide has a high degree of chemical inertness, making it resistant to rusting and chemical assault from a wide range of bases, acids, and other compounds. Because of this, it can be used in challenging conditions where other materials might deteriorate, like the processing of chemicals, the aerospace industry, and nuclear purposes.

Significant Strength: Silicon carbide is suited for applications in structures where rigidity and strength are essential, like in aviation components, solid ceramics, and automobile brakes. It has excellent tensile strength and great stiffness.

Silicon carbide has semiconducting qualities, which make it appropriate for application in electronic parts like transistors, diodes, and sensors. Because of its broad bandgap, it can operate at high voltages and temperatures, which makes it perfect for electrical components and higher-temperature applications of sensors.

The ability to keep its qualities even at extremely high temperatures is provided by silicon carbide's outstanding thermal stability. This qualifies it for usage in applications that require high temperatures such as heat exchangers, gas turbine parts, and missile nozzles.

These are a few of silicon carbide's key characteristics, which make it a special and adaptable substance with uses in a variety of fields, including the aerospace, automotive, electronic goods, energy, and defense industries. It is a valuable material for a variety of demanding applications due to its unique combination of extreme temperature support, hardness, chemically inertness, and electrical properties.



Fig 4.7. Silicon Carbide Powder

4.6.3 Titanium diboride powder:

The earth does not naturally contain TiB_2 . A ceramic substance called titanium diboride (TiB_2) is made up of the atoms of boron and titanium. Numerous high-temperature processes, such as carbothermal elimination by thermite reaction among titanium oxide and boron oxide, hydrogen decrease of boron halides in with the presence of the metal or its halides, or immediate reactions of titanium Ti or its

oxides/hydrides with elemental boron over 1000°C, can produce titanium diboride powder. To produce finer titanium diboride TiB_2 in huge quantities using several synthesis methods, solid-state processes, and electrochemical synthesis have been devised.

An incredibly hard ceramic with high heat conductivity, oxidation stability, and resistance to mechanical erosion is titanium diboride (TiB_2). Its density is 4.52 g/cm³, and its point of melting is roughly 3230 °C. The most stable titanium-boron compound is titanium boride. The substance cannot be found naturally however, it can be created through the carbothermal elimination of TiO_2 and B_2O_3 . TiB_2 interacts with alkalis, nitric acid, and sulfuric acid but is opposed to oxidation in air at temperature up to 1100 °C as well as hydrochloric and hydrofluoric acids. TiB_2 may be formed by machining with electrical discharge and can be utilized as a cathode material in the smelting of aluminum since it is a reasonable electrical conductor. Titanium boride micron granules are frequently used in structural applications such as ceramic sintered parts, cutting tool composites by ceramic armor nozzles, wear parts, seals, liquid metal crucibles, and metalizing boats. It is renowned for its superior thermal, mechanical, and electrical characteristics, which makes it suitable for a variety of applications.

4.6.3.1 Applications of TiB_2 :

- TiB_2 is a possibility for a variety of applications due to its great hardness, incredibly high melting point, and chemical inertness.
- ballistic armor.
- Although its comparatively high density and difficulties in producing structured components make it less appealing for this kind of application than some other ceramics, its blend of high hardness and slight durability makes it appealing for ballistic armor.
- Smelting of aluminum
- TiB_2 is used as a cathode in Hall-Heroult cells for the primary smelting of aluminum due to its chemical inertness as well as its conductivity to electricity.

Additionally, it can be used to handle molten metals and as a boat for metal evaporation.

Other Applications:

Titanium diboride is a candidate for use in cutting tools, cutting seals, wear parts, and composites with other substances because of its high hardness, wear resistance, and moderate strength. When combined with other main oxide ceramics, TiB_2 is utilized to create composite materials that have the added benefit of boosting the matrix's strength and fracture toughness.

4.6.3.2 Properties of titanium diboride powder

Hardness: With a Mohs hardness rating of roughly 9-10, titanium diboride is one of the hardest substances ever discovered. Due to its outstanding wear resistance and high hardness, it is perfect for applications where substantial amounts of abrasion or wear are anticipated.

Melting point: Due to its high melting point of $2980\text{ }^{\circ}\text{C}$ ($5396\text{ }^{\circ}\text{F}$), titanium diboride is appropriate for use in high-temperature applications. Because it maintains its stability and strength even at high temperatures, it can be used in harsh situations.

Thermal conductivity: When compared with other ceramics, titanium diboride has a comparatively low heat conductivity, which makes it an effective thermal barrier material. Due to its ability to resist heat transfer, it is capable of being used as a coating to shield materials from higher temperatures, making it perfect for use in jet engines, high-temperature furnaces, and other applications that require high temperatures.

Electrical-conductivity: Titanium diboride has strong electrical conductivity, which makes it suitable for use in applications related to electronics and electricity. In order to provide electrical conductivity, it has been utilized as a conductive addition in a variety of materials, including composites and coatings.

Chemical stability: The majority of acids and alkalis do not cause titanium diboride to react with them, and it is corrosion-resistant and chemically stable. Due of its corrosion resistance, it can be used in corrosive chemical settings.

High strength: Due to its great strength and hardness, titanium diboride is a good choice for structural applications. As a result of its high toughness for fractures, it can endure significant mechanical pressures without cracking.

Low density: Titanium diboride has a relatively low density compared to other ceramics, which makes it lightweight. Because of this characteristic, it is appealing for uses where minimizing weight is crucial, including those in the automotive and aerospace sectors.

Thermal expansion: Titanium diboride has a small value for the coefficient of heat expansion, which means that temperature changes have little effect on its dimensional stability. This makes it practical for applications where dimensional accuracy and thermal stability are essential.

High hardness, a very high melting point, poor thermal conductivity, excellent electrical conductivity, chemically stable, high strength, low density, and a relatively low thermal expansion are just a few of the unique qualities that titanium diboride powder possesses. These qualities make it ideal for a variety of applications, which includes resistance to wear coatings, thermal barriers, conductors of electricity, and structural components in hot and harsh environments.



Fig 4.8 Titanium Diboride Powder

4.6 NON-DESTRUCTIVE TESTS:

Non-destructive testing, also known as NDT, is a style of testing or assessment where no harm is done to the object being tested or evaluated. Instead, it employs a variety of methodologies to examine and analyze the material's attributes, make-up, and composition to find any flaws or other anomalies that might impair its functionality or safety. Visual evaluation, ultrasonic analysis, testing with magnetic particles, liquid penetrant experiments, radiography testing, eddy current (EC) testing, and Acoustical emission testing are only a few examples of the techniques used in NDT. According to the item being examined and the intended use, each of these procedures is intended to find various kinds of flaws or defects.

NDT is frequently utilised in sectors like oil and gas, aerospace, automotive, construction, and manufacturing, where dependability and safety are crucial considerations. Before they cause major malfunctions, which can be expensive in terms of interruptions, repairs, potential injuries, or even fatalities, it enables the discovery of flaws and deficiencies. As it may assist pinpoint areas for development and guarantee that products adhere to industry norms and laws, NDT is also a crucial instrument in quality assurance and product development. Overall, Nondestructive Testing is a crucial component of contemporary industry and is crucial in assuring quality, dependability, and safety.

4.7.1 Advantages of Non-destructive test:

Cost-effective: One of the main advantages of NDT is that it can help save costs in the long run. Unlike destructive testing methods that require materials or structures to be destroyed in order to obtain results, NDT techniques allow for inspection, testing, and evaluation without causing any damage. This eliminates the need for costly repairs or replacements, which can save time and resources.

Safety: NDT methods are non-intrusive and do not pose any risks to the safety of personnel conducting the tests or the integrity of the materials or structures being tested. Destructive testing methods, on the other hand, may require cutting, grinding, or other forms of material removal, which can be hazardous and potentially compromise the structural integrity of the item being tested.

Increased productivity: NDT techniques are typically fast and efficient, allowing for quick and accurate evaluation of materials or structures. This can help streamline production processes and reduce downtime, leading to increased productivity and improved efficiency.

Preservation of assets: NDT allows for the assessment of the condition of materials or structures without causing any damage, which helps in preserving the integrity of the assets being tested. This is particularly beneficial for valuable or irreplaceable items, such as historical artifacts, heritage structures, or critical components of infrastructure, where destructive testing would not be feasible or desirable.

Inspection of hidden defects: NDT techniques can detect defects or flaws that may not be visible to the naked eye, such as cracks, voids, corrosion, or internal structural anomalies. This allows for early detection of potential issues, which can prevent catastrophic failures and ensure the safety and reliability of materials or structures.

Environmentally friendly: NDT methods are non-invasive and do not generate waste or produce harmful emissions, making them environmentally friendly compared to destructive testing methods that may generate waste or hazardous byproducts.

This aligns with sustainable and eco-friendly practices, which are increasingly important in today's environmentally-conscious world.

Compliance with regulations and standards: NDT techniques are widely recognized and accepted by various industry standards and regulatory bodies, making them a reliable and accepted method for evaluating the quality and integrity of materials or structures. Compliance with regulations and standards is critical for ensuring safety, reliability, and quality in industries such as aerospace, automotive, and energy, where stringent requirements are in place.

4.7.2 Disadvantages of NDT:

Limited Sensitivity: NDT techniques may have limitations in terms of their sensitivity to detect very small defects or flaws, especially those that are located deep within a material or component. The sensitivity of NDT methods depends on various factors such as the kind of material being tested, the shape and size of the defect, and the type of NDT technique used. In some cases, very small or subtle defects may be missed, leading to false-negative results.

Interpretation Challenges: Interpreting the results of NDT can sometimes be complex and require skilled personnel with specialized training and expertise. The data obtained from NDT techniques may be subject to interpretation, and false-positive or false-negative results can occur due to human error or limitations in the interpretation process. Interpretation challenges can arise due to various factors, such as the complexity of the inspected component, the presence of multiple layers or materials, and the influence of external factors on the NDT results.

Cost and Equipment Requirements: NDT techniques often require specialized equipment and trained personnel, which can increase the cost of testing. The initial investment in NDT equipment and training can be significant, especially for more advanced techniques. In addition, periodic calibration and maintenance of NDT equipment may be necessary to ensure accurate and reliable results, adding to the ongoing costs.

Limitations in Identifying Some Forms of Defects: NDT techniques may not be suitable for the detection of certain types of defects or flaws in specific materials or components. For example, some NDT methods may be less effective in detecting cracks that are oriented parallel to the direction of the applied stress, or in detecting defects in materials with high levels of porosity or inhomogeneity. In certain situations, other testing techniques or several NDT techniques could be necessary to achieve a thorough evaluation of the material's or component's integrity.

Surface Sensitivity: Many NDT techniques are surface-sensitive, meaning they may only detect defects or flaws that are located near the surface of the material or component being tested. Deeper defects may be missed, especially if the surface is coated or has a rough texture. Additional measures such as surface preparation, removal of coatings, or use of multiple techniques may be required to access subsurface defects, which can add complexity and time to the testing process.

Limitations in Some Materials: NDT techniques may have limitations when applied to certain materials or components. For example, some techniques may not be suitable for testing materials with high electrical conductivity, high melting points, or materials that are transparent to the testing method being used. In such cases, alternative NDT techniques or testing methods may need to be employed, which can add to the complexity and cost of the testing process.

4.7.3 X-Ray diffraction (XRD) analysis

X-ray diffraction is an analytical technique which is used to determine the atoms' arrangement in a crystal structure. When X-rays are directed towards a crystal, the atoms in the crystal lattice bend or diffract them, producing a distinctive pattern of dispersed X-rays. In general, X-ray diffraction is an important tool for studying the atomic and molecular structure of materials and has revolutionized our understanding of the physical world.

Information about the arrangement and orientation of the atoms within the crystal lattice can be gleaned from scattered X-rays pattern. Scientists can ascertain the crystal structure and learn more about the material's physical and chemical properties

by examining the angles and intensities of the diffracted X-rays. X-ray diffraction (XRD) analysis is used in many fields, including material science, chemistry, physics, and biology. It has many applications, including identifying unknown compounds, characterizing crystal structures, studying the behavior of materials under different conditions, and designing new materials with specific properties.

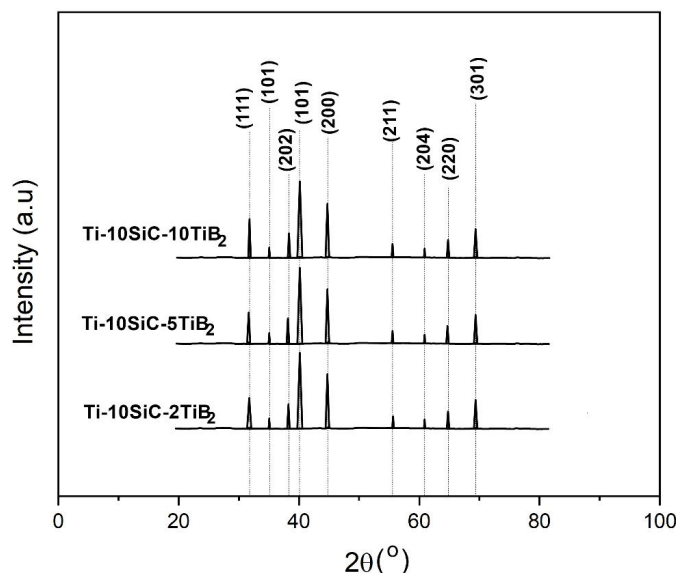


Fig 4.9 XRD pattern of Ti-SiC-TiB₂ composites

Ti peaks: 40.12° (101), 38.33° (202), 35.34° (101), and 69.77° (301) in accordance with JCPDS card # 44-1294

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

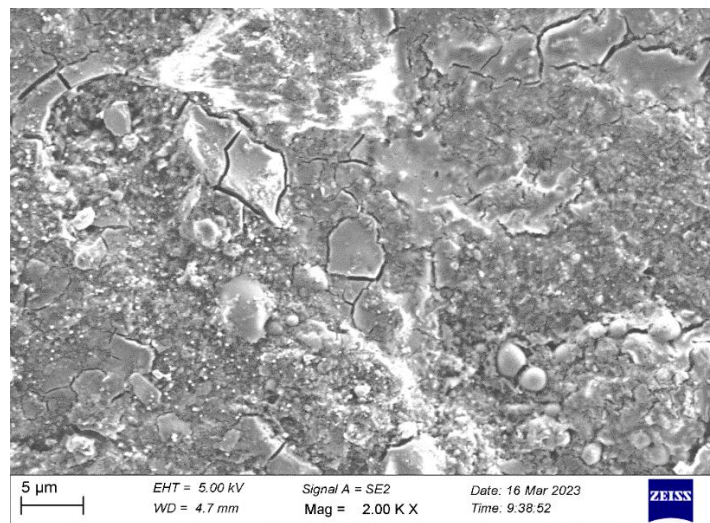
TiB₂ peaks: 34.12° (111), 56.23° (211), 62.36° (204) in accordance with JCPDS card # 35-0741

4.7.4 Scanning electron microscopy (SEM)

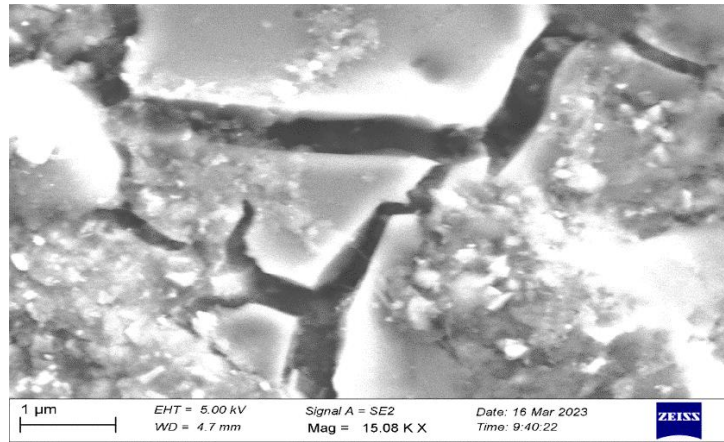
A scanning electron microscope, also known as SEM, is a type of microscopy that produces high-resolution, three-dimensional images of a sample's surface using a beam of energetic electrons. In contrast to optical microscopes, which create

images using visible light, scanning electrons on a sample's surface creates an image in an SEM. The SEM apparatus is made up of an electron source, an electron gun, and a device known as a detector that collects the produced electrons in a vacuum chamber. To avoid charging the sample while imaging, a tiny layer of conductive material, such as gold or carbon, is often applied to the sample. Secondary electrons are released from the sample's surface when the electron beam is focused on the sample. The sample is then imaged using the secondary electrons that were found. By altering the contrast and brightness, you can highlight particular details in the image.

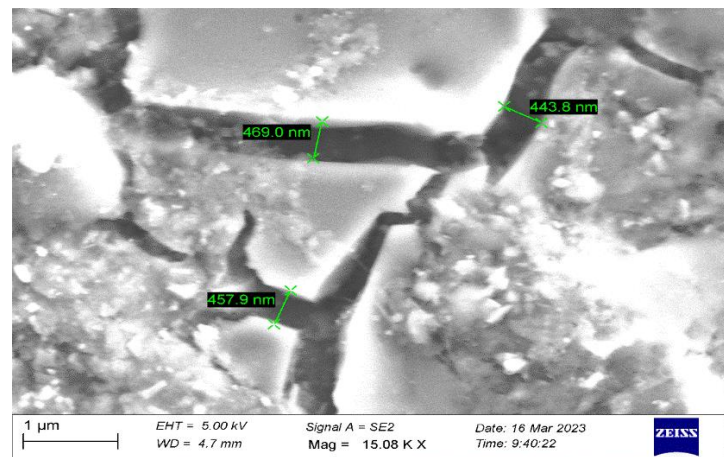
In comparison to other microscopy methods, SEM has a number of benefits, including excellent resolution, being able to produce images that are three-dimensional, and the capacity to examine a wide range of objects, including biological specimens, metals, and ceramics. It is frequently used to examine the surface appearance, structure, and composition of specimens at the micro- and nanoscale in the domains of materials science, biology, geology, and other sciences.



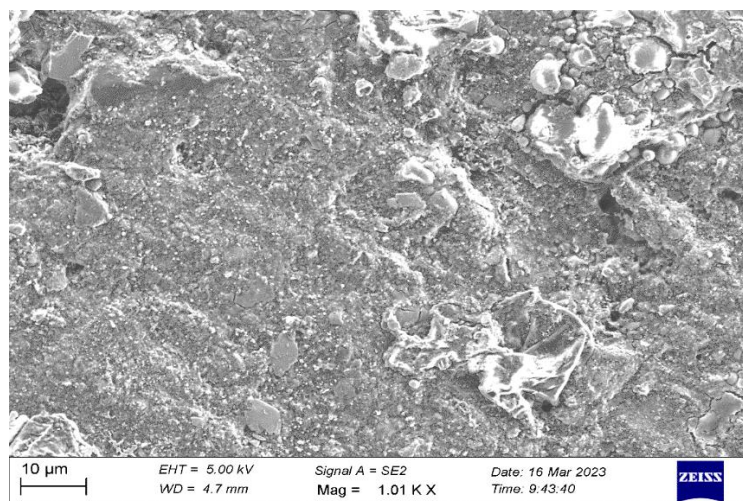
(A)



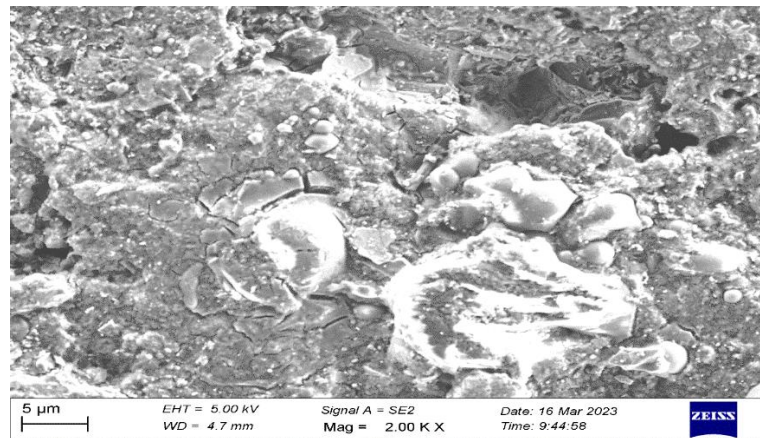
(B)



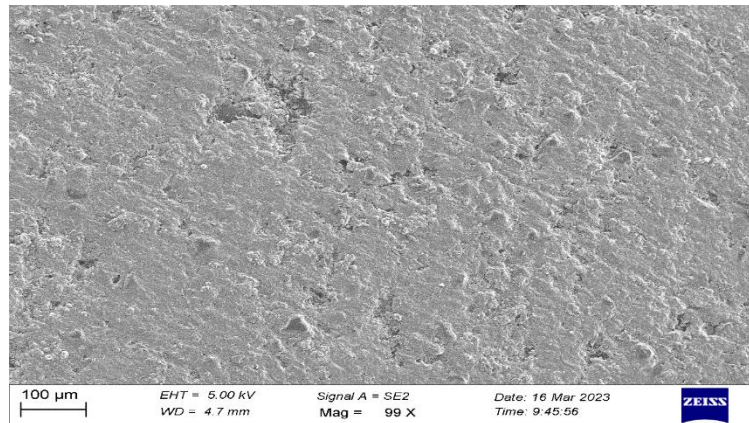
(C)



(D)



(E)



(F)

Fig 4.10 Images obtained by scanning electron microscopy (A-F)

4.8 DESTRUCTIVE TESTS:

In order to evaluate a test specimen's durability, strength, and other qualities, destructive testing involves purposefully putting it under strain, stress, or other forms of harsh conditions. In this kind of testing, the sample is typically partially or completely destroyed or damaged in order to collect data or assess its performance. To make assured that components and materials fulfill particular standards and requirements, destructive testing is frequently employed in the engineering, production, and construction industries. For instance, destructive testing can entail stretching a sample of a metal alloy to the point where it breaks in order to determine

its ultimate tensile strength. Destructive testing can reveal important details about the behaviour and characteristics of components and materials in challenging circumstances, despite the fact that it may seem wasteful given that the test specimen is destroyed. The design, functionality, and safety of items and structures can all be improved with the use of this knowledge.

4.8.1 Advantages of destructive test:

Accurate Failure Analysis: Destructive testing provides a definitive understanding of the failure mode and the limits of a material or component. By subjecting the specimen to extreme conditions until it fails, the exact point of failure and the mode of failure can be identified, allowing for accurate analysis and determination of the failure's root cause. This information can be used to improve design, manufacturing, and material selection in order to avoid similar failures in the future.

Validation of Design and Manufacturing Processes: Destructive testing can be used to validate the design and manufacturing processes of a material or component. By subjecting samples to destructive testing, engineers can determine if the manufacturing processes and design are producing components that meet the required specifications and performance criteria. This can help identify any weaknesses or flaws in the design or manufacturing process, leading to improvements and optimizations.

Cost-Effective: Destructive testing can often be more cost-effective compared to other types of testing, such as non-destructive testing (NDT) methods. Non-destructive testing methods, such as X-ray, ultrasound, or magnetic particle testing, can be expensive to implement and may not always provide as accurate or conclusive results as destructive testing. In some cases, destructive testing can be a more cost-effective option, especially when testing a small number of samples or when the cost of material or components is relatively low.

Simplified Test Setup: Destructive testing typically involves simple and straightforward test setups compared to some non-destructive testing methods, which can require complex equipment and procedures. Destructive tests are often easier to set up and execute, which can save time and resources in the testing process.

4.8.2 Disadvantages of destructive test

Loss of Test Specimens: Destructive testing typically involves destroying the test specimens in the process, which means that the samples cannot be reused for further testing or other purposes. This can result in increased costs for obtaining new specimens, especially if the material or component being tested is expensive or difficult to obtain.

Limited Sample Size: Destructive testing often requires a significant amount of material or component to be sacrificed for testing, which may not always be feasible or practical, especially for rare or limited-supply materials. This can result in limitations in sample size and statistical significance of the results obtained.

Inability to Detect Internal Defects: Destructive testing methods often only reveal surface defects or properties, and may not be able to detect internal defects or hidden flaws that can affect the performance or durability of a material or component. This can result in the incomplete or inaccurate characterization of the material or component being tested.

Time and Cost: Destructive testing can be time-consuming and costly, as it may involve the preparation of multiple test specimens, conducting multiple tests to obtain statistically significant results and the need for specialized equipment or facilities. This could be added to the overall cost of the testing process, especially for large-scale or complex structures.

Safety Risks: Destructive testing can pose safety risks to personnel and equipment, especially if it involves high-stress conditions, large-scale structures, or hazardous materials. Proper safety precautions must be taken during destructive testing to ensure the well-being of personnel and the integrity of the testing environment.

4.8.3 MECHANICAL PROPERTIES – MICROHARDNESS and TENSILE testing:

By measuring the size or depth of an impression left by an indenter while being subjected to a certain force, a technique known as microhardness testing can be used to assess the hardness of various materials. It is frequently employed to gauge the degree of hardness variation present on a material's surface or to assess the hardness of tiny thin, or sensitive materials. A rough diamond or just Vickers indenter is driven into the sample's surface during microhardness testing with a specified force, typically between 1 and 1000 grams. The hardness is then estimated by considering the measurements of the indentation and the force that was applied after the depth or diameter of the indentation is measured under a microscope.

Microhardness testing's key benefit is that it makes it possible to accurately assess the breaking strength of delicate or thin samples, such as coatings, thin films, or small particles in a polycrystalline material. In order to comprehend a material's mechanical properties, it can also be utilized to quantify the hardness gradient over its surface. In order to assess the quality and hardness of diverse materials, microhardness testing is frequently used in the fields of material science, metallurgy, and engineering. When designing and optimizing materials for diverse uses, it can offer useful information regarding the material's ability to stand up to wear, deformity, and fracture.

4.8.3.1 Vickers microhardness:

A diamond indenter is driven into the surface of the substance that is being tested with a particular load during the Vickers microhardness testing procedure. Depending on the applied load, the indenter creates a square in shape impression with a diagonal length ranging from 10 to 300 micrometers. A microscope is used to measure the indentation's size visually and record it as its Vickers hardness number (HV). The load applied in kilograms-force is divided by the indentation's surface area in square millimeters to determine the material's Vickers hardness number. The measurement is guaranteed to be unaffected by the size or form of the indenter using this method of determining the hardness value.

Vickers microhardness testing, which may deliver precise results at extremely small scales, is particularly helpful for determining the hardness of delicate substances or small regions of larger materials. As it can identify modifications in the material's microstructure, it is especially helpful for determining the hardness of substances that have undergone heat treatment or surface treatment. In general, the Vickers microhardness assessment procedure is a useful instrument for precisely and non-destructively determining the hardness of materials, and it has many crucial uses in both materials research as well as industry.

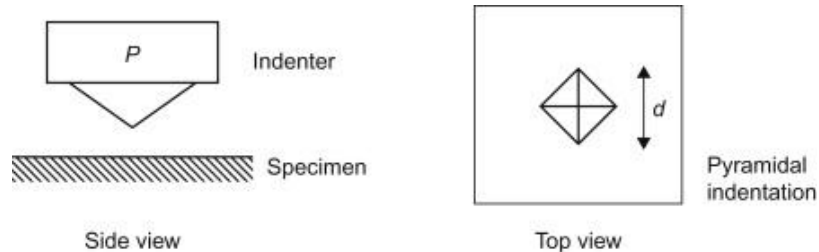


Fig 4.11 Vickers Hardness Test

4.8.3.2 Tensile test:

Mechanical testing known as tensile testing is used to ascertain a material's qualities when it is under tension. In order to assure the quality and capacity of materials, this kind of testing is frequently employed in engineering and manufacturing. A sample of the substance is put through a controlled, progressively increasing tension during a test known as tensile testing, which is often conducted using a device called a tensile evaluation machine. The test determines how the material reacts to the applied force; this response is typically depicted by a stress-strain curve. The mechanical characteristics of the material, such as its elastic properties, strength, and ductility, are shown by the stress-strain curve. Elasticity is

the capacity of a material to regain its initial form after distortion, whereas strength is the capacity of a material to withstand deformation and fracture under stress. The ability of a material to deform without breakage or fracturing is referred to as ductility.

A variety of products in order including metals, polymers, ceramics, and composites, can be tested using tensile testing. The test's findings can be used to quality assurance procedures, the development and production processes, and material selection.

4.8.4 Ultimate tensile strength:

The ultimate tensile strength (UTS), also known as the ultimate strength or simply the tensile strength, is a mechanical property that describes the highest stress that a material can endure before failing or breaking in a test of tensile strength. Tensile testing is a common method used to identify the mechanical properties of materials, particularly metals, and alloys. In a tensile test, a standardized specimen of the material is subjected to an axial load or force, which is applied along its longitudinal axis. The specimen is gradually pulled apart, causing it to elongate until it ultimately fractures. The tensile test measures the stress (force per unit area) applied to the material as it is being deformed, and the corresponding strain (change in length per original length) that occurs. The UTS is the highest stress point on the stress-strain curve obtained from the tensile test. It represents the point where the material experiences the highest stress just before fracture. At this point, the material is typically stretched to its maximum deformation, and the cross-sectional area of the specimen starts to reduce due to necking, which is a localized reduction in the material's diameter. The UTS is an important parameter that indicates the material's strength and ability to resist external loads without breaking. The UTS is generally reported in units of stress, such as pounds per square inch (psi) or megapascals (MPa), and it is an important parameter used in material selection and design calculations. Materials with higher UTS values are generally considered stronger and more applicable for applications where high strength is required, such as in structural components, automotive parts, and aerospace applications. However, it is important

to note that the UTS is just one of many mechanical properties that should be considered in materials selection, as different materials may have different combinations of properties that make them suitable for specific applications.

4.8.5 yield strength

The yield strength is a mechanical characteristic that identifies the level of stress at which a material starts to distort permanently without going back to its initial shape when the applied tension is removed. Tensile testing is frequently used to determine it, and it is a crucial parameter in materials science and engineering. A common method for determining a material's mechanical characteristics, including yield strength, is tensile testing. A test specimen usually cylindrical or rectangular in shape is tugged by a testing device in opposing directions until it breaks in a typical tensile test. Recorded during the test are the applied force and the specimen's consequent elongation. The stress-strain curve generated from the tensile test is commonly used to calculate the yield strength. The strain is measured by dividing the change in length of the specimen by its original length, while the stress is obtained by dividing the applied load by the specimen's original cross-sectional area. The stress-strain curve, which often displays multiple separate sections, illustrates how stress changes in relation to strain. The stress at which a material experiences a particular level of plastic deformation, frequently 0.2% or 0.5% strain, is known as yield strength. Hooke's Law, which outlines the linear connection between stress and strain in the elastic area of the stress-strain curve, describes the stress at which a material starts to depart from that relationship. In simple terms, it is the tension at which a material starts to permanently change shape without regaining it when the stress is released. As the highest stress a material can withstand without suffering considerable plastic deformation, the yield strength of a material is a crucial factor in the selection and design of materials. It is used in a variety of industries, including manufacturing, structural engineering, automotive, and aerospace, to assess the safety margins and operational characteristics of materials. Variables like temperature, strain rate, and material composition can all affect the yield strengths of various materials.

4.8.6 Ductility

A tensile test is frequently used to determine a material's ductility, which is a measure of its capacity for deformation under tensile force without breaking. The mechanical test known as a tensile test, often referred to as a tension test or a pull test, is frequently used to describe the mechanical characteristics of materials, notably metals, and alloys. An axial stress or tensile force is applied to a sample of the material during a tensile test, causing the sample to deform along its length. The sample is typically in the form of a standardized specimen with a specific shape and dimensions, such as a cylindrical or rectangular shape. As the tensile force is applied, the sample undergoes elongation, or stretching, along the axial direction. The amount of elongation is measured using strain gauges or extensometers, which are devices that can accurately measure the change in length of the sample. The ductility of a material is typically characterized by the amount of plastic deformation it can undergo before fracture occurs. Plastic deformation is a permanent deformation that occurs in a material when it is subjected to stress beyond its elastic limit. Elastic deformation, on the other hand, is a temporary deformation that is reversible when the stress is removed. Ductile materials are capable of undergoing significant plastic deformation before fracturing, while brittle materials tend to fracture with little or no plastic deformation. In a tensile test, the ductility of a material can be determined by measuring various parameters, including the ultimate tensile strength (UTS), the yield strength, and the elongation at fracture. The UTS is the maximum stress the material can withstand before fracturing and is an indicator of the material's strength. The yield strength, which indicates a material's capacity to sustain plastic deformation without fracture, is the stress at which the material starts to deform plastically. The elongation at fracture, which measures the material's ductility, is the ratio of the sample's length at the moment of fracture to its starting length. Many metals and alloys, which are ductile materials, are able to experience significant plastic deformation prior to fracture, and as a result, they display high extensibility at fracture values. Due to this quality, they are useful for operations like metal forming, structural engineering, and automotive parts that call for materials that can sustain strain without fracture. Brittle materials, on the other hand, including some polymers and ceramics, have a

tendency to shatter with little to no plastic deformation and, as a result, have a low elongation at fracture values.



Fig 4.12 Tensile Test (UTM)

4.9 FRACTOGRAPHY- SEM-EDX:

Fractography techniques commonly used in materials science and engineering include scanning electron microscopy (SEM), optical microscopy, transmission electron microscopy (TEM), and other advanced imaging techniques. These techniques allow for detailed examination of the fracture surfaces at different magnifications and resolutions, which can reveal the characteristics of the fractures, such as crack morphology, crack propagation paths, deformation features, and other relevant information.

Fractography is an important tool in failure analysis, materials characterization, and materials design, as it provides valuable information about the behavior of materials under different conditions and loads. It helps engineers and scientists

understand the mechanisms and causes of fracture in materials, and can be used to improve the design and performance of materials and structures to prevent failures in general applications, such as automotive, aerospace, civil engineering, and other industries.

CHAPTER-5

RESULTS AND DISCUSSION

The relationship that exists between stress (force per unit area) and strain (deformation or change in shape) of a material is represented graphically by a stress-strain curve. This curve is used to comprehend a material's mechanical characteristics, such as its strength, stiffness, and ductility, and to assess how well it will function in various applications. The material's ultimate strength is reached when the stress and strain are at their highest levels, after which the material breaks or fractures. The stress-strain curve typically exhibits a stress peak at the ultimate strength, then a stress decline as the material experiences strain to soften.

A material's mechanical behavior can be described using the stress-strain curve's general form as well as additional factors like Young's modulus, yield strength, ultimate strength, and strain hardening exponent. The following Stress-Strain diagram of Ti-SiC-TiB₂ composites given below clearly shows the ultimate tensile strength of the hybrid composite is decreasing with the increasing percentage of titanium diboride and the yield strength as well as the ductility of the samples was increased with the increasing percentage of TiB₂. The result of Vickers microhardness also proved that the hardness of the samples gradually increased and the determined values of the Vickers microhardness are given in the table. The fractography images show the reinforcements (SiC and TiB₂) present on the main metal (Ti) and the sample's dimple, tearing, and pores which are all formed during the powder metallurgy process.

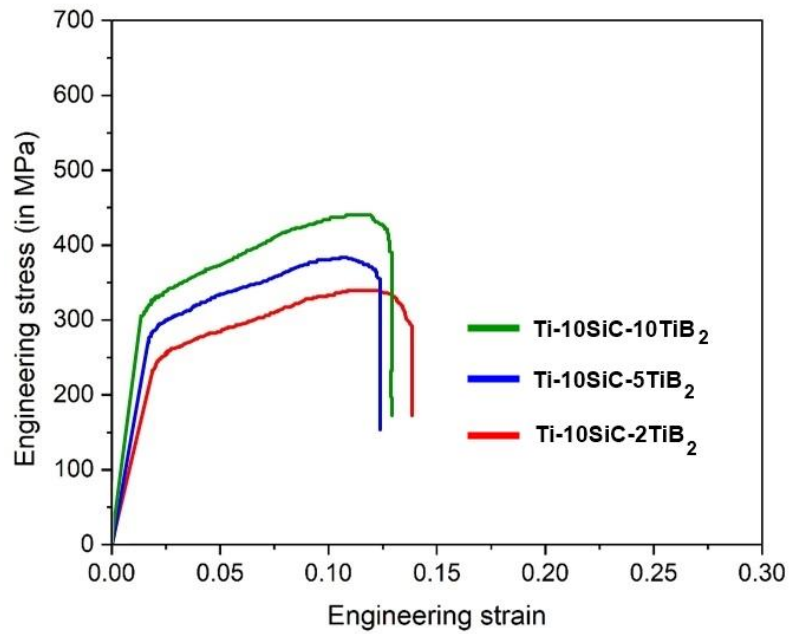


Fig 5.1 Stress-Strain diagram of Ti-SiC-TiB₂ composites

Table 5.1 Mechanical properties of Ti-SiC-TiB₂ composites

Metal matrix composites	UTS (in MPa)	0.2% YS (in MPa)	Ductility (%)	Vickers microhardness (in HV)
Ti-10SiC-2TiB ₂	436	239	8.7	125
Ti-10SiC-5TiB ₂	361	268	10.8	152
Ti-10SiC-10TiB ₂	323	307	12.3	215

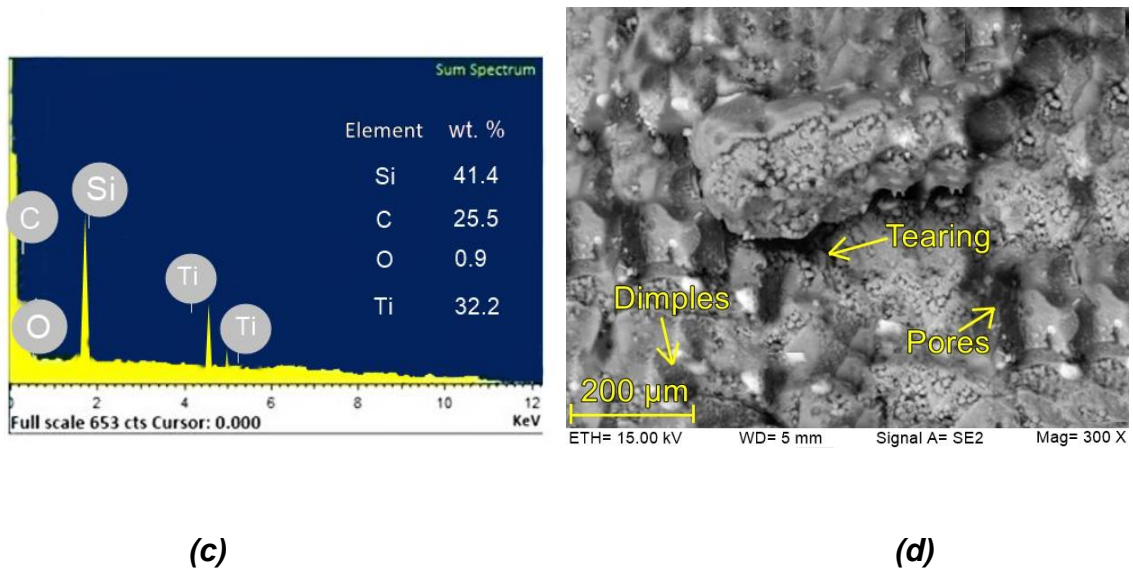
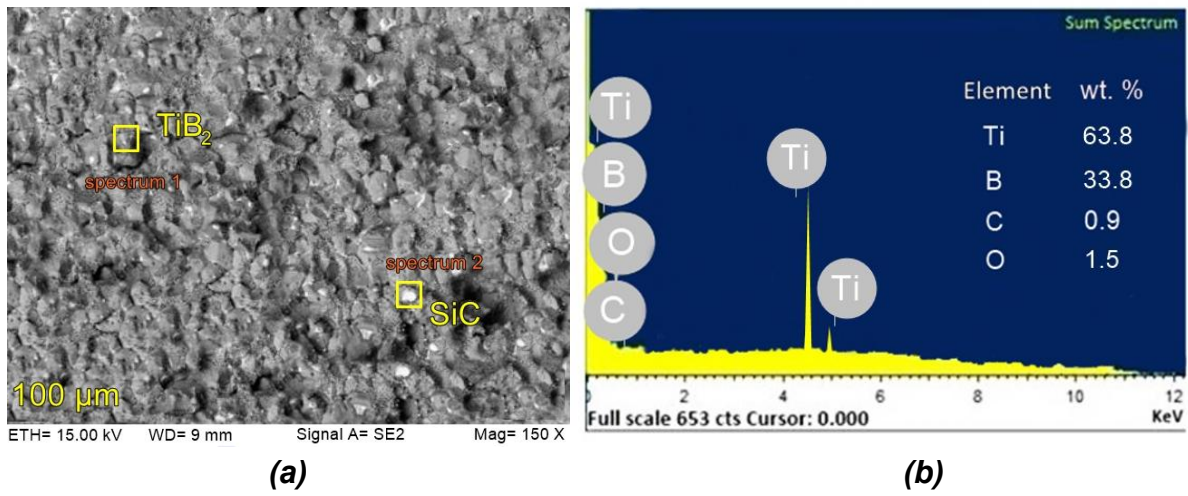


Fig 5.2 SEM micrograph of the fractured surface showing (a) SiC and TiB₂ particles and their (b-c) corresponding EDS spectrum and (d) fracturing methods

CHAPTER-6

CONCLUSION

The report gives a thorough rundown of the fabrication process with an emphasis on the mechanical and wear properties of titanium MMCs that combine various reinforcements. With regard to the method, the benefits and drawbacks are briefly highlighted. the hardness and microstructure of the composite had been notably influenced by the sintering temperature. A thorough discussion of the mechanism underlying the increase in tensile strength, impact strength, and hardness was conducted. A brief discussion of various wear surface mechanisms is followed by relevant research. In general, most of the reinforcements added to the main metal have resulted in high microhardness, yield strength, and ductility. It showed higher resistance against indentation and compressive force as compared with composite without reinforcement. Finally, this analysis will assist in identifying the research background as well as the difficulties in producing titanium composites while demonstrating good behavior with regard to contemporary usage. This work can be further extended by fabricating the composites with different casting methods and comparing their effect on the mechanical properties of composites.

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