Chapter - 1

INTRODUCTION

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1.1 Overview

Advanced ceramics are newer ceramic materials that are playing a very important role in today's world and have brought a revolution in the application of ceramics in the 21st century. The special characteristics of these ceramics materials are their low density compared to metals, high modulus of elasticity (stiffness), higher strength at elevated temperature, resistant to high temperature creep, very good dimensional stability even at high temperature, high compressive strength, higher hardness, resistant to corrosion and oxidation, good electrical resistivity, high value of thermal conductivity with wide range of thermal expansion coefficient. Due to these special characteristics ceramics are more suitable for high temperature applications when compared with metals and polymers. These unique and superior properties of advanced ceramics have placed them in a most attractive position, not only in the field of widen applications but also in cost effectiveness [1-3].

Advanced ceramics for various engineering applications are also referred as technical ceramics. Due to their combination of superior properties, technical ceramics are widely used in high temperature applications, mechanical and process engineering along with electrical and electronics engineering. Technical ceramic materials can be broadly divided in oxide and non oxide ceramics. Oxide ceramics generally include materials that are basically composed of metal oxides. Some of the important oxide ceramics are aluminium oxide (Al_2O_3) and zirconium oxide (ZrO_2). They are generally resistant to oxidation, chemically inert, but show electrically insulating properties with low electrical and thermal conductivity, sometimes with complex and costly manufacturing methods. Non-oxide ceramics on the other hand include ceramic materials based on compounds of boron, carbon, nitrogen and silicon. Important non-oxide ceramics are silicon nitride (Si_3N_4) and silicon carbide (SiC), aluminium nitride, boron carbide, boron nitride and titanium carbide (TiC) etc. They generally contain a high proportion of covalent compounds. Due to this, they possess excellent properties like light weight, high melting point, high thermal and chemical stability, very high elastic modulus, high strength and hardness, advantageous electrical and thermal conductivity properties combined with high wear, corrosion and oxidation resistance. This allows their use in advanced engineering applications for automotive and refractory industries, aerospace materials, electrical and electronic products [3-5].

Among various non-oxide metal carbides, Titanium carbide (TiC) is one of the most important and potential metal carbide used in advanced ceramics. This is because, it possesses many outstanding suitable properties such as high melting temperature, high hardness, high modulus, low density, superb chemical stability, good electrical conductivity, good thermal shock resistance, higher wear and corrosion resistance as well as very good wettability and high temperature stability [6–9]. Because of this reason, titanium carbide has become the promising candidates in cutting tools, grinding wheels, wear-resistant parts and coatings, high-temperature heat exchangers, magnetic recording heads, turbine seals, bullet-proof vests, forming dies, and light-weight amour pieces etc. [10-11]. TiC is transition metal carbide of group IV with refractory nature. Its crystal structure and bonding nature are somehow responsible for its superior properties for which titanium carbide (TiC) occupy a unique position in the spectrum of engineered ceramics offering many desirable advantages than the other non-oxide ceramics in common usage.

1.2 Properties of Titanium carbide

Titanium carbide (TiC) has recently been receiving high commercial attention, due to a wide variety of application possibilities that arise from their unique specified properties compared to other ceramic materials. Some of its important positive properties have been highlighted below. A comparison of properties of TiC with some of the common non-oxide ceramics that are commonly used for advanced structural applications (SiC, TiB_2, WC, Si_3N_4, TiN etc) is given in Table 1.1[12].

Table 1.1: Properties of common Non-oxide Ceramics [12]

	Physical	Thermal			Electrical and Magnetic		Mechanical					
	Specific gravity (kg/m^3 x 10^{-3})	**Melting or dissociation (d) temperature (K)**	**Linear expansion coefficient (300-1300K) (10^{-6}/K)**	**Conductivity (W/m.K)**	**Electrical resistivity (x 10^8 ohm.m)**	**Magnetic susceptibility (x10^6) (1/mol)**	**Elastic modulus (GPa)**	**Poisson's ratio**	**Micro-hardness at 1N load (GPa)**	**Bend strength (MPa)**	**Compressive strength (GPa)**	**Fracture toughness ($MPa.m^{1/2}$)**
AlN	3.26	2572(d)	5.0	180.0	$>10^{19}$	-	320	0.25	15.3	320	3.8	2.8
B_4C	2.52	2743	5.54	28.0	1000.0	-	427	0.19	31.5	340	6.6	3.2
BN	2.28	2600(d)	2.0	15.0	1.7×10^{19}	-	60	-	0.1	20	0.3	16.0
SiC	3.21	3103(d)	5.12	41.0	4×10^5	-	408	0.14	30.0	350	6.3	3.9
Si_3N_4	3.18	2151(d)	2.6	29.5	$>10^{19}$	-	315	0.27	15.0	800	4.4	6.0
TiB_2	4.52	3193	4.6	24.0	9.0	31.3	541	0.11	25.5	450	5.7	6.4
TiC	4.92	3290	7.95	17.2	200.0	5.0	494	0.19	30.0	500	1.4	2.0
TiN	5.44	3223	8.7	28.9	40.0	37.0	390	-	19.9	260	1.3	-
WC	15.8	3073(d)	5.76	29.3	19.2	9.8	737	0.24	30.0	530	4.3	6.0

Crystal structure

Titanium carbide is the most common and widely used transition metal carbide. It appears as a light to dark brown or black, powdery substance. In its pure form, when not mixed with other substances, it is fine and feels slippery to the touch. It has a rock salt (B1) type of crystal structure (Figure 1.1) that is face cantered cubic with space group: Fm3m. The lattice parameter a (distance between the nearest carbon atoms) is 0.4327 nm. Titanium (Ti) and carbon(C) atoms are at the origin and (1/2, 1/2, 1/2) positions respectively. Within the atom Ti and C are octahedrally coordinated with each other. Thus this carbide has small and uniform carbon-carbon distance resulting in a wide range of carbon stoichiometry. Generally in the NaCl structure each ion is encircled by six immediate neighbours of the opposite charge. This exceptionally well-organized packing allows for confined neutralization of charge and makes for stable bonding. Materials that crystallize in this type of structure tend to have comparatively high melting points [3, 13 and 14].

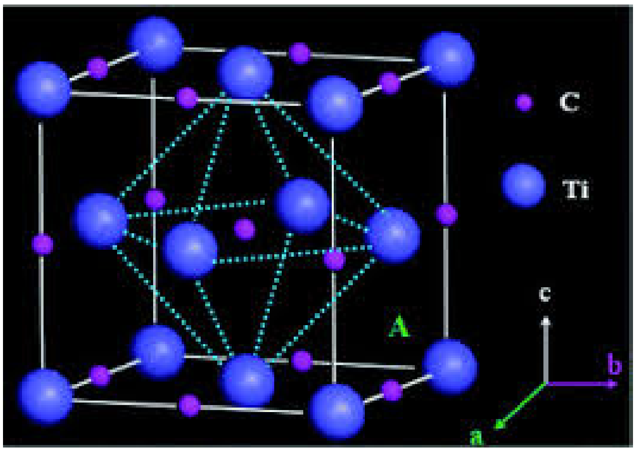

Figure 1.1: Crystal structure of Titanium Carbide [15]

For ductility, polycrystalline materials require a minimum number of independent slip systems or the directions in which slip can occur. The function of the slip system is to transfer crystal deformation from one grain to the neighboring grain. Metallic materials usually have the necessary number of slip systems, even at room temperature. Ceramic materials generally do not possess these, which is the main reason of their brittleness. Among the various carbides titanium carbide is not prone to brittleness unlike tungsten carbide because of its cubic crystal structure. Tungsten carbide suffers from brittleness due to its HCP crystal structure and also it shows lower oxidation resistance in air than Titanium carbide. This is because the unique nature of slip of TiC at high temperature (nearly 800 ^{o}C) on {111} planes in <110 >direction. This results in a grain to grain compatible deformation due to availability of slip systems and transition from brittle to ductile behaviour in TiC. As it is a non-stoichiometric compound its properties such as electrical conductivity, chemical stability and mechanical strength can be achieved up to required level by changing its stoichiometry [3, 16-19].

The reasons for the superior properties of ceramics are their strong primary bonds that hold the atoms and make the ceramic material. In most of the ceramic materials, the primary chemical bonds found are in actual fact a mixture of ionic and covalent types. These primary bonds in ceramics make them among the strongest, hardest, and most refractory materials known. Research works on bonding nature of TiC, show that it is a combination of metallic, ionic and covalent characteristics, in which Ti-C covalent bonding is the predominate one. A certain degree of iconicity can be detected, combined with a smaller amount of metallic bonding. The presence of covalent bonding and some residual covalence in bonds of mixed nature is believed to result in mechanical properties like high hardness, lower plasticity or brittleness, and thermodynamic features like high melting temperature. Whereas, the higher electric transport properties of TiC shows the presence of metallic resistivity. Due to presence of partly metallic bonding these carbides show an excellent thermal conductivity and higher interfacial adhesion to metals. The activity of transition metal titanium is higher in comparison to other metals which may result in higher wettability of TiC than other carbides. According to most of researchers, TiC is categorized either as a covalent material or carbide with mixed bonding nature [3, 19-21].

Chemical properties

Titanium carbide contains 20.05 % carbon theoretically. With cubic crystal structure of NaCl type, it has high solvency with other carbides. It is chemically stable and shows inert behaviour in the medium of hydrochloric and sulphuric acids. But TiC is easily soluble in oxidizing chemical like aqua regia and hydrofluoric or nitric acids. It also shows solubility in alkaline oxidizing melts. TiC forms nitrides above 1500 ^{o}C when comes in contact with a heated atmosphere containing nitrogen. At higher temperatures it is attacked by chlorine gas and gets oxidized in air [22]. Ceramics are more resistant to corrosion than the metallic materials. The chemical composition and the microstructure of the compound are the main reason for low corrosion rates. Non-oxide materials are more resistant to corrosion by metallic melts when compared with oxide ceramics. Non-oxide ceramics are less heavily attacked by alkaline solutions than some oxide ceramics. Titanium carbide has higher chemical resistance and is relatively resistant to oxidation up to 1100 °C due to the formation of titanium oxides. These thick layers of oxides act as good solid-state lubricants with excellent properties that give protection from further oxidation and make TiC suitable for high performance applications [4, 23].

Mechanical properties

The mechanical properties of ceramics mainly include its density, bending strength, elastic modulus and hardness. The relative density has a significant effect on the properties of the ceramic. Density of TiC is 4.94 gm/cm^3, which is lower than that of tungsten carbide although both show similar hardness. This gives a chance for possible weight reductions in various mechanical applications. The available uniform porosity that is responsible for comparatively low density also gives the advantage of ability to withstand thermal shock. The bending strength is the most important factor for assessing the strength of components and for dimensioning them. The size, shape, surface and, in few cases, the inhomogeneities in the microstructure resulting from the production process are somehow responsible for a component's bending strength. This carbide shows very good bend strength of 500 MPa, compressive strength of 1.4 GPa. Its fracture toughness is 2 MPa.m$^{1/2}$[4, 12].

The elastic modulus E of almost all non-oxide ceramics is always higher than that of steel. This results in an elastic deformation of only about 50 to 70 % of what is found in steel components. The advantage of high stiffness is that forces experienced by bonded ceramic/metal constructions must predominantly be taken up by the ceramic material. TiC has high Young's modulus of 494 GPa and a shear modulus of 188 Gpa with a poison's ratio of 0.19. TiC shows higher elastic modulus than SiC, B_4C, AlN, and Si_3N_4. TiC is hard refractory metal carbide of Mohs hardness 9-9.5. It has high Vickers hardness of 28-35 GPa, high hardness means a high resistance to deformation and is associated with a considerable modulus of elasticity. Technical ceramic products are therefore characterised by their stiffness and dimensional steadiness. The high hardness of ceramic materials results in encouraging wear resistance [4, 12].

Tribological properties

Ceramics are good for tribological applications. Tribology covers the entire field of friction and wear, together with lubrication and associated boundary layer interactions. TiC as a ceramic material shows higher wear resistance. Wear is of immense economic importance, because the service lives of machines and equipment are highly dependent on it. The wear resistance of a material strongly depends on its type and microstructure. TiC shows a very low coefficient of friction. Friction generally refers to the force that resists relative motion. The coefficient of fiction is the ratio of the frictional force to the normal force between the surfaces. This property is very much important for both structural and mechanical applications [4].

Thermal properties

TiC shows excellent thermal stability and has a very high melting temperature of approximately 3290 ^{o}C. The table 1.1 clearly shows that Titanium carbide (TiC) has higher melting temperature, than all the compounds. Ceramics materials basically possess lower thermal conductivity when compared with metals such as steel or copper. However inducing some porosity in the ceramic, can enhance the insulating properties. Some amount of porosity is available in TiC due to wide range of carbon stoichiometry. Thus, TiC has high thermal conductivity of 17.2 W/mK with a linear thermal expansion coefficient of 7.95×10^{-6}/K at 300-1300 K. Matching of thermal expansion coefficient is important while used as a reinforcing phase in metals as they possess higher coefficients than ceramics. TiC has higher thermal expansion coefficient than WC, SiC and TiB_2 that are most widely used. Thermal shock is the sensitivity of a material to temperature gradients leading to failure. The reason of this is internal mechanical stresses generated due to temperature gradient and brittleness of the material. TiC has a high thermal shock resistance compared to others. This may be due to the transition from brittle to ductile behaviour at high temperature and available porosity resulting from the short bonds and wide range of carbon stoichiometry [4, 12].

Electrical properties

Most technical ceramics possess a high electrical resistivity even at high temperatures but titanium carbide shows very good electrical properties. It has high electrical conductivity (39×10^6 S/Cm) with an electrical resistivity of 200×10^8ohm.m. So it can be used as a conductor at high temperatures. Electrical resistivity of TiC is very low when compared with that of SiC, B_4C, AlN, and Si_3N_4 [4, 12].

1.3 Application of Titanium carbide

Recently TiC has a great demand for use in various applications which require operations at high temperature, long life, weight savings of the components along with the process be cost effective. Due to lower density of TiC, it is desirable for applications which demand materials of light weight. TiC is suitable for electrical discharge machining, due to its good electrical conductivity, which overcomes the problem of shaping such hard material. In mechanical chemistry and the microelectronics industry there is wide use of TiC for conducting diffusion barriers. It also acts as an additive to plastic and rubber parts [24, 25].

Cutting tools

Very hard carbide or nitride materials such as WC, TiC, TaC, TiCN are basically used for cutting tool materials. Among which TiC being characterized by high strength, high thermal and chemical stability, short bonds and high hardness, is widely used for this purpose. Due to very good thermal conductivity which results in low temperature gradients, TiC is very suitable for use high speed cutting tool applications for reducing thermal stresses and cracking. As it possess excellent chemical stability, so it decreases the chemical interaction between the cutting tool and the work piece, thus reducing the crater wear. After tungsten carbide-cobalt TiC-based ceramics have been used worldwide in the cutting tools industry, as high temperature ceramics, in the form of a hard metal or cermets [24, 26-27].

Cermets

TiC is effectively used in cermets due to its low friction coefficient and higher oxidation resistance in comparison to cemented tungsten carbide. Titanium carbide generally combines with metals like nickel, to form cemented carbides or cermets, which have resulting properties greater than those of either constituent. Cermets basically possess high hardness and wear resistance available from carbide phase with the mechanical and thermal shock resistance offered by the metallic binder phase. These factors make them useful for various applications concerning large mechanical and thermal stresses. Titanium carbide based cermets are most widely used in the manufacture of cutting tools, grinding wheels, and coated cutting tips. Properties like ceramic-matrix bond strength, fracture toughness and hardness of individual components are generally responsible for abrasive wear implementation of cermets. The stoichiometry of titanium carbide strongly determines the bond strength between the carbide and metallic binders along with its hardness. Titanium carbide is thermodynamically stable over a wide composition range, with the bond becoming stronger as the Ti: C ratio in the ceramic phase rises. So organization of the titanium carbide stoichiometry may thus allow control of the wear resistance of cermets through its hardness and strength of bonding with the matrix [28-30].

As a substitute to WC in machining material

TiC is widely used in different branches of machine construction due to its high strength and hardness. It can be used as an alternative to tungsten carbide (WC), which is the most widespread metal carbide used as machining material, because of its comparable properties on the subject of melting temperature, higher hardness, and oxidation and wear resistance. To produce cemented carbides, WC uses cobalt as a binder material. Currently 10% of the world's consumed cobalt (Co) is used as binder material for WC components. This binder is imported from foreign and occasionally politically unstable sources. TiC compounds can use nickel (Ni) as a binder which has more stable sources and costs only half as much as Co. Nickel is much cheaper than cobalt; therefore, TiC has a cost advantage over WC in the production of cemented carbides. Moreover, TiC's properties of melting temperature, hardness, and oxidation resistance are superior to those of WC. Another advantage of TiC is that it can be united with other ceramics like aluminium oxide (Al_2O_3), silicon nitride (Si_3N_4) and silicon carbide (SiC) for the manufacture of structural components used in high temperature, erosive and/or corrosive applications [31-34].

In Coatings

Recently, out of a wide variety of available material system for hard, wear resistant protective coatings, titanium carbide has increased its technological curiosity because of its good mechanical properties like low density, high hardness, and good corrosion and wear resistance properties that sustained up to 400 ^{o}C. Titanium carbide is a well-known coating material used in industrial applications due to its high a high melting temperature, good thermal shock resistance, high thermodynamic stability with metal matrix and good chemical and physical sputtering resistance under bombardment by highly energetic particles. Having advantages like higher hardness, lower densities and lower friction coefficients, thermal sprayed composite coatings of TiC bonded with different metals are assured to be an exceptional substitute for the conventionally used WC or Cr_3C_2-based coatings, being potentially effective in many wearing resistant applications. Another important application is in the area of plasma and flame spraying processes in air, where titanium carbide-based powders show higher-phase stability than tungsten carbide based powders [27, 35-38].

As reinforcement in composites

The superior properties of TiC have resulted in its extensive use as a reinforcing phase in composites and super alloys. In particular, the material has shown great potential in reinforcement and hardening of various materials including light metals and alloys (e.g., titanium-, aluminium-, and nickel-based materials), intermetallic compounds, as well as the advanced ceramic systems [39]. TiC particles also used as reinforcement in polymeric materials. This application of TiC has been elaborated below in detail.

1.4 Titanium carbide reinforced composites

In the present era composite materials are playing a vital role and becoming more dominant as they can help to improve our quality of life. Composites find immense applications in the areas of automobiles, naval, aerospace, buildings, pipelines and many more structural and engineering products. A composite material can be defined as a combination of two or more different materials, which results in better properties than those of the individual components. The two constituents are reinforcement and a matrix [40, 41]. In the composite, matrix material generally surrounds and supports the reinforcement materials while the reinforcements improve physical and mechanical properties of the matrix [42]. Broadly, composite materials can be classified into three groups on the basis of matrix material. They are: a) Metal Matrix Composites (MMC), b) Ceramic Matrix Composites (CMC), c) Polymer Matrix Composites (PMC).The reinforcement material is embedded within the matrix. In addition to reinforcing the matrix, it also changes the physical and mechanical properties of the matrix, such as strength, hardness, wear resistance, friction coefficient, or thermal conductivity etc. Role of reinforcing materials depend on its type. Reinforcements for the composite materials can be fibers, particles or whiskers [43]. Composites reinforced with discontinuous particles show more isotropic properties whereas fibers and whisker add a certain amount of directionality [44-46]. Composites use particles of various inorganic and organic materials, depending upon their compatibility. These particles can be oxides, carbides, borides, nitrides and many more. Among the various the particles used for composite fabrication, ceramic particles play a very important role [46].

Titanium carbide particles are effectively used as a reinforcement phase in composites due to its superior mechanical properties, unique electrical properties and high-temperature strength. Important advantages of TiC over other metal powders and intermetallic compounds are not only its high electrical conductivity but also its oxidation resistance and chemical stability. It improves the various properties of composites like strength, hardness, wear and corrosion resistance by controlling its microstructure and makes composites as value-added products. Fine-grained TiC can improve yield strength of the composites through dispersion and grain size mechanisms, and improve toughness by hindering crack propagation [47]. Therefore, continuous research processes are being carried out on improving the properties of TiC reinforced composites and to make it less expensive for future applications.

TiC reinforced Metal Matrix Composites

An extensive research has been carried out by various researchers on titanium carbide reinforced metal matrix composites. Metal matrix composites (MMCs) are combination of a metal as a matrix and a reinforcing phase. TiC is considered a necessary reinforcement in metal matrix composites due to its superior hardness and high chemical stability. TiC with high hardness and excellent thermal stability is a very good reinforcement in Fe-based composites, which is applied in tribological applications like wear resistance parts and high performance tooling. Due to its high hardness, melting point, and thermodynamic stability as well as availability, TiC is significantly used as a reinforcing phase in MMCs' coatings, like Ni and steel based composites. Titanium carbide based composites with nickel alloys and iron alloys are presently used in high performance applications where wear and corrosion are the main sources of material failure. Recently in the industrial scale production of composites, TiC is the most prevalent reinforcing material after SiC and Al_2O_3 [48-52].

Different type of metals like Aluminium, Magnesium, Copper, Nickel, iron and Titanium can be used as matrix in a composite. Out of these metals, in most of the MMCs, aluminium is the most frequently used metal matrix material due to its low density and excellent cast ability. Aluminium matrix composites (AMCs) reinforced with ceramic particles exhibit high strength, high elastic modulus and improved resistance to wear, creep and fatigue compared to unreinforced metals that make them promising structural materials for aviation and automotive industries[53–61]. Al-based MMCs with ceramics like SiC, Al_2O_3, TiC and TiB_2 as the reinforcement phase have been widely studied in numerous research works [53, 62-66]. However, TiC is particularly attractive due to high hardness, elastic modulus, low density, excellent wettability and low chemical reactivity with molten aluminium. Hence, Al–TiC composites occupy a unique position in the family of metal matrix composites due to their excellent wear resistance, high strength-to-weight ratio and good mechanical properties. The improvement of such properties in Al-TiC composites completely depends on the amount and uniform distribution of TiC particles [67–69]. So there is a need for studying the effect of TiC particles on various mechanical properties of Al-based composites. The detail literature survey has been elaborated in chapter 2.

TiC reinforced Polymer Matrix Composites

Ceramic particulate reinforced polymer composites have become one of the new areas of explosive research due to the high potential use of these materials in mechanical and structural applications in automobile, marine and aerospace industries. Particles when incorporated in polymer matrices improve their thermal, physical and mechanical properties for various applications. These composites frequently subjected to wear in most of their applications. Tribological performance of these composites greatly improves by addition of hard ceramic particles [70, 71]. Lots of research works have been carried out using different ceramics such as Al_2O_3, TiC, and SiC by varying the size and volume fraction of the particles. It has been studied that carbides give more protection to the polymer matrix than the oxides. TiC has the potential to be used as a filler material in various polymer composites. Composite systems consisting of glass-fiber reinforced epoxy resin and particles of titanium carbide can be considered as a novel class of smart materials. TiC particles may play a role to sustain the external load, while stresses between the fibers may be transferred by the epoxy matrix. The synthesized composite is expected to have higher wear resistance [72, 73]. Therefore the tribological properties of the TiC reinforced polymer matrix composites need to be studied adequately. The literatures have been elaborated in chapter 2 in detail.

As titanium carbide possesses so many important properties and plays a vital role in the world of composites, it has been always a need to produce titanium carbide powder from a cheap source of raw material by using suitable methods and short period of time, so making it less expensive for advanced technological applications. From the last decade, synthesizing titanium carbide powder has been explored as an area of vigorous research. There are different methods for preparing titanium carbide powder such as carbothermal reduction of titanium dioxide (TiO_2) powders by using carbon [74, 75] or carbonaceous organic material [76, 77], direct carburization reaction between metallic titanium and carbon [54, 34], carbothermal reduction of carbon-coated titanium dioxide [30], sol–gel and microwave carbothermal reduction methods at low temperature [78] and gas phase reaction of $TiCl_4$ with appropriate gaseous hydrocarbons [79]. However, direct reaction of metallic titanium and carbon is an expensive process due to high cost of metallic titanium used and high energy required for the process [80]. Also titanium chloride used as precursor for TiC preparation is an expensive material [33]. Among all these processes, the most widely used process for commercial production of titanium carbide is carbothermal reduction of titanium dioxide in the presence of carbon [81]. This has been elaborated in chapter 2 in detail.

1.5 Aim of present work

Based on the above discussions the primary objective of the present investigation is preparation of Titanium carbide powder by a novel synthesis method and its application as reinforcement in improving the mechanical properties of metal matrix composites and polymer matrix composites. The specific objectives of the work with detailed literature survey are given in chapter 2. Lay out of the thesis is given below.

1.6 Layout of the thesis

To meet the above objectives, investigations have been carried and results have been analysed and concluded. On that basis the thesis has been organized in the following manner.**Chapter2** deals with detailed literature survey on the preparation of titanium carbide powder and preparation of TiC reinforced aluminium matrix and polymer matrix composites. This chapter also covers the scope and objectives of the present work. **Chapter 3** comprises a detailed description of materials and methods, experimental details used and procedures followed. This chapter also covers the characterization methods applied for present investigation. **Chapter 4** deals with the results from the experiments conducted on preparation of titanium carbide powder from the mineral ilmenite in a thermal plasma reactor. An in-depth discussion has been done on the obtained results. **Chapter 5** deals with the results and discussion on preparation of TiC reinforced aluminium matrix composite by hot pressing method. **Chapter 6** deals with the results and discussion on preparation of TiC reinforced polymer matrix composite by hand-lay-up method. **Chapter 7** summarizes the results of the present investigations, by deriving a list of major conclusions drawn from different chapters. The **References** cited within each chapter are given after chapter 7. At the end, **List of publications** covers the publications of researcher Sangita Mohapatra related to the present topic of research work, in various journals and proceedings.