# Review on Fe-TiC Composites for Industries

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*Particulate reinforced ferrous based metal matrix composites has been directed towards improving wear resistance of steel or cast iron by incorporating some reinforcing phase , e.g. Carbides. The present article provides a review on the various synthesis of TiC reinforced Fe based composites, i.e., powder metallurgy, liquid metal particulate mixing and In-situ production, and other alternating processing routes. Mechanical properties such as elastic modules hardness, flexural strength and impact energy of Fe-TiC composites. Highlighting the advantages and disadvantages associated with the Fe-TiC composites. The review concludes by underlining the importance of further research in industries.*

***Key Words*: *Titanium Carbide, Cast-Penetrating, Powder Metallurgy, In-Situ generation, Microstructure.***

## 1. INTRODUCTION

Composites are a leading candidature for applications where a good combination of strength and plasticity is required. Among all kinds of composites, ceramic particles reinforced metal matrix composites have excellent wearbility, corrosion resistance, and high temperature creep resistance **[1-2].** Although much of the metal matrix composites interest is centered on the lighter structural metals to attain improved strength and stiffness, there has been a significant interest in developing particulate iron-based Metal matrix composites (MMC's) owing to their excellent wear resistance, cutting performance with improved toughness, and significant cost reduction over existing materials **[3-5].** It is well established that the incorporation of hard second-phase particles deliberately added to ferrous matrices can significantly improve certain material properties. In the group of engineering materials, iron-based composites containing Titanium Carbide (TiC) have received particular attention. They exhibit the toughness and machinability associated with conventional alloy steels combine with significant improvement in hardness and wear resistance **[6-7].**

MMC's dispersed with discontinuous particulates gain a considerable amount of attention as an important engineering materials in automotive, aerospace and defense sectors and also to an extent in general engineering because of their improved properties (low density, excellent castability, good wear resistance and fine physical properties) and much lower cost of production.**[7-8].** Composites materials with steel matrix and ceramic particle reinforced provided scope for producing relatively in expensive wear- resistant materials.**[9-11]** Metal matrix composites that use ceramic particles for reinforcement have good toughness and wear resistance, when applied to wear resistant materials such as cutting tools and press dyes.**[12-13]** Ferrous based MMC's have attracted the considerable attention of researchers in the field of material science in recent years as they possess potentially improved properties over commercial metals and alloys. The typical advantages cited are increased hardness, wear resistance and better elevated temperature properties **[14-15].** Also, there are many complex problems in the development of particulate reinforced steel composites. The fabrication process of this kind of MMC's by conventional powder metallurgy has several limitations for the homogeneity of the material. In the recent studies, solidification processing has emerged as one of the most economical and versatile technique to produce steel based MMC's **[16].**

TiC is one of the most important compounds among transition metal carbides, due to its promising physical properties, such as high melting temperature(3140$^oC$), a high boiling temperature(4820$^oC$), high Vickers hardness (25-35 Gpa) high young's modulus ( 410-450 Gpa) low density (4.93 g-cm$^3$), high flexural strength (240-400N/mm$^2$), good thermal conductivity (21W/m$^2$XK), high resistance to corrosion and oxidation, high abrasion resistance, high thermal shock resistance. So it is widely used for cutting material, abrasion, anti-wear and aerospace materials. At the same time, it can also be used as a substitute for tungsten carbide in cermet's because they have similar properties of high hardness and wear resistance **[17-21].** Ceramic particles of TiC have high hardness and thermal stability and can be used to reinforce iron based composites **[22-23].**

In recent years, TiC particles reinforced MMC's have received much attention in the world **[5].** TiC strengthened tool steel has been characterized for good combined thermal stability and mechanical properties. Many products such as FERROTIC™, TiC ALLOY™, FERRO-TITANIT™, have been developed and commercialized **[24-25-26].** It is well established that the incorporation of hard ceramic particulates to ferrous matrices can significant improve certain material properties example, hardness, wear resistance etc. Particulate reinforced steel matrix composites have been proposed for use as wear and corrosion resistant part in the chemical and process industry, or as suitable for the more expensive cemented carbides **[27-28].**

## 2. COMPOSITE PROCESSING

Different processing techniques have evolved over the last three decades in an effort to optimize the structure and properties of particulate reinforced MMC's. Different processes for fabrication of steel matrix based composites are given in Figure 1.

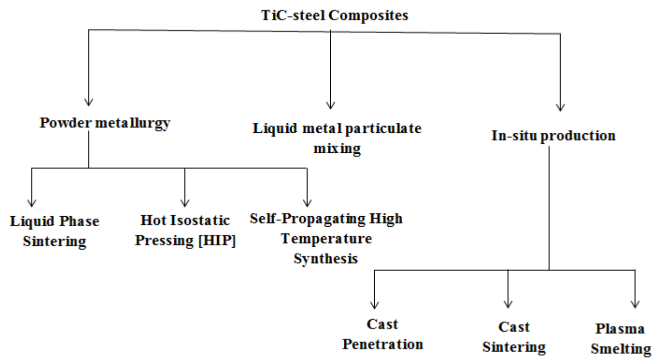


**Figure. 1 Methods of producing TiC reinforced steel matrix composites**

### 2.1 Powder metallurgy method.

Powder metallurgy techniques can be profitably used with discontinuous fibers whiskers and particulate reinforcement's matrix metal powders and reinforcement materials are thoroughly blended and compacted to consolidate. These composites are highly billable and wear resistance and mainly used as cutting tools in machining industries.

### 2.1.1 Liquid- phase sintering. [LPS]

In powder metallurgy a well-known and established manufacturing route is liquid-phase sintering [LPS]. In this method a powder mixture consisting of the alloy powder and sometimes a binder/lubricant is pressed into a green body. This green body is then heated to a temperature where a liquid phase is formed. This green body is consolidated into a dense body by three stages namely(i) particle arrangement due to surface forces within the component; during this stage capillary forces dominated the densification and this leads to the elimination of the porosity.(ii) solution re-precipitation type of rearrangement of the particles; in this stage Ostwald ripening and coalescence of the solid phase will dominate and this leads to increase of the grain size, especially at high sintering temperature.(iii) final pore closure and grain growth, this third and final stage occurs when a generally solid skeleton has been formed by coalescence .

### 2.1.2 Hot isostatic pressing [HIP]

In this method first series,10 vol% of FeTi particles were dispersed in metal matrix and powder graphite is added to Low Alloy Steel [LAS] + FeTi in stoichiometric proportion of TiC amounting to 0.25 times the Ti mass of FeTi. No graphite was added to High Alloy Steel [HAS]+FeTi and White Cast Iron [WCI]+FeTi because the matrix powders of high carbon content used as carbon donors for the TiC formation. The powder mixtures is filled into cans, which evacuated, sealed, hot isostatically pressed at 1125 $^{o}$C and 105 Mpa for 4hours to get fully dense materials.

### 2.1.3 Self Propagating High temperature synthesis [SHS]

Steel matrix particulate composites were processed by direct addition of powders to molten medium carbon steel. Fe-TiC powder was produced using a self-propagating high-temperature synthesis [SHS] reaction and consisted of a dispersion of fine TiC particles in an iron binder.

### 2.2 Liquid metal particulate mixing

Solidification processing route for particulate reinforced steel composites have the advantages of cheapness, flexibility and simplicity and ease of production of composites with complex shapes. Liquid metallurgy method of making particulate composites consists of introduction, retention of solid particles in liquid alloy followed by casting into suitable moulds.

### 2.3 In-situ production

In situ techniques involve a chemical reaction resulting in the formation of a very fine and thermodynamically stable ceramic phase with in a metal matrix. As a result, the reinforcement surfaces are likely to be free from gas absorption, oxidation or other detrimental surfaces reaction contamination, and the interface between the matrix and the reinforcement bond therefore tends to be stronger.

### 2.3.1 Cast penetration method

A cast penetration technology combined with insitu synthesis is applied a TiC particle reinforced iron matrix composite. The raw material used in this experiment is cast iron and titanium wire. Titanium wires with the diameter of 0.7 mm were uniformly fixed at the bottom of the graphite crucible. Then liquid cast iron was poured to the graphite crucible at about 1400 $^{0}$C and cooled to room temperature, leading to the formation of Fe-TiC composite**[1-2].**

### 2.3.2 Cast sintering technique

Cast sintering technique is the method of producing composite materials. In this method, the composition of the low melting point component and carbide forming component powders were mixed in a ball mill for 24 hours and pressed into pellets using a steel pressure die. The pellets were bonded to the wall of the casting mold after baking steel at706 $^{0}$C for 4 hours; liquid steel at 2146 $^{0}$C was poured into the moulds.

### 2.3.3 Plasma smelting of Ilmenite

In this process, initially ilmenite and coke powder of required composition thoroughly mixed and charged in the hopper of the powder feeder. Mild steel scrap charged in to the graphite crucible. The mixed ilmenite and coke powder directly poured to the molten mild steel. Argon gas is used as plasmagen gas and passed through the top electrode at the rate of 1 liter per minute. After ascertaining the complete melting of mild steel scrap, the mixture of ilmenite and coke powder is fed into the crucible of the powder feeder. After complete feeding of the smelting charge, the plasma arc continued for 15-20 minutes to complete the reaction. Patrik Person et al. **[29-30]** produced composite by liquid-phase sintering of Fe-TiC. Metallographic analysis of the specimens after sintering has been carried out and that reveals porosity, as indicated by the density measurements. And he also studied on wettability, and agglomerates are penetrates by the melt. It also clears that the agglomerates still appear as clusters, creating an inhomogeneous microstructure on microscope.

By K. Jayashankar et al. **[3-5]** an attempt has been made to synthesize in-situ Fe-TiC composites by two routes, namely static bed and in-flight thermal plasma processing of ilmenite with coke as a reluctant, the energy consumption for preparing composites is expected to be low of the two routes, the in-flight plasma route seems to be quite promising owing to its better dispersion of TiC in the Fe matrix. Pagounis, Talvite and Lindroos**[1-2, 6]** worked extensively on metal matrix composites on TiC reinforced white iron matrix tool steel, by hot isostatic pressing. And also to assess the influence of the reinforced volume fraction on the microstructure and abrasion resistance of iron matrix composites.

Bolton and Gant **[31-35]**studied the composite made through conventional sintering route and studied the microstructural development of high speed steel based composites reinforced with TiC. Terry and chinyamakobvu **[4-5]** Produced composite of Fe-TiC by adding molten Fe-Ti alloy to carbon in the form of coal in an induction furnace, and microstructure of the composite produced showed a uniform distribution of discrete TiC particles.

## 3. MICROSTRUCTURE AND INTERFACE OF TIC-MATRIX

TiC particles distributed in a matrix is the source of strengthening of the composites. Adequate and coherent bonding between matrix and particles is essential to permit loading the carbides to the maximum strength. For better understanding of the bonding behavior, strength data are needed as a function of fabrication parameter, metal properties, chemical and mechanical compatibility and characteristic of the interface region such as flows and unbounded areas. It is found from Figure 2 that fine TiC particles form micro networks in the composites that are beneficial by protecting the matrix against wear.


**Figure 2. SEM micrograph of Fe-TiC composites showing micro network of TiC particles**

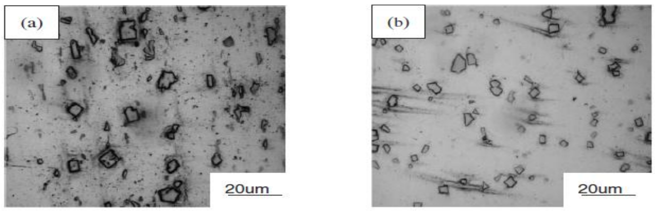


**Figure 3. Optical micrograph of TiC strengthened steels (a) as forged low carbon steel (b) as forged medium carbon steel**

Qian LiN Wu et al. **[44-45]** prepared TiC strengthened steels using low carbon and medium carbon and 5 mass% of TiC were added to these steels to see the effect of TiC on the microstructure. The optical micrograph of the steel studied is shown in Figure 3. It can be seen that the most TiC particles had a faceted morphology and were uniformly dispersed in the steels low carbon and medium carbon. Figure 4a reveals the presence of TiC particles in as cast composites as single phase matrix. Various phases observed in the microstructure have been labeled in Figure 4b at higher magnification.

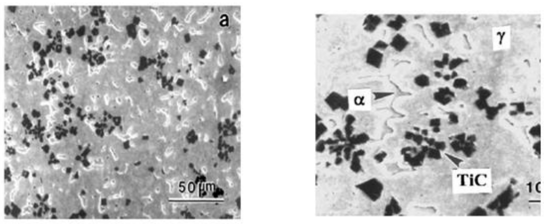

**Figure 4. The SEM morphology of the (a) as- cast composites, (b) at higher magnification**

Figure 5 indicates the back scattered electron image of the 10 vol% Fe-TiC composites. It can be seen that some large speheralic titanium-rich particulates are distributed in the matrix. A great number of thin rod-like phases can be observed at a higher magnification (Figure 4b) which seems to be a eutectic morphology.

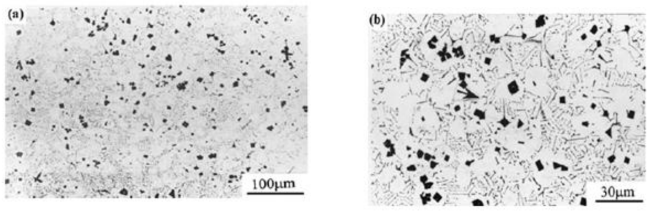


**Figure 5. SEM micrograph of the TiC-Fe composites, a) low magnification b) High magnification**

Parashivamurthyet.al [41] studied microstructure of composites of Fe-TiC using scanning electron microscope. As shown in Figure 6 exhibits that TiC particles are homogeneous and uniformly distributed into the matrix.

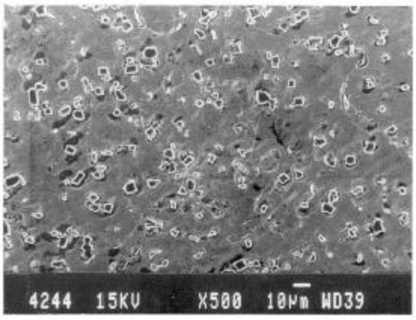


**Figure 5. Scanning electron micrograph of 21.6% volume fraction of TiC**

The processing method adopted, composite particulars, micro structural details, properties determined and objectives of various investigators are summarized in the table 1 as shown below.

For formation of TIC in the molten metal Gibbs free energy plays role in the molten Fe-Ti-C. Heguo Zhu et al. [**61**] worked on the formation of standard Gibbs free energy explains in details about on formation of Fe-TiC in the molten Fe-Ti-C. Figure 7 shows how the standard forming Gibbs free energy of the possible products like TiC, $Fe_2Ti$ and $Fe_3C$ vary with the temperature. It is noted that the standard Gibbs free energy of formation for TiC is lowest, compared to that of $Fe_3C$, and $Fe_2Ti$, therefore the formation of TiC phase thus favored over of $Fe_3C$, and $Fe_2Ti$, meaning that Tic phase would appear in the composites.

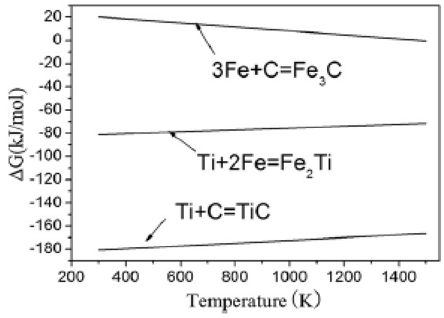


**Figure 7. Shows forming of Gibbs free energy of the possible products as a function of temperature [61]**

QianLin Wu et al. **[44]**, studied the thermodynamics concerning TiC particles in the molten Fe-Ti-C based alloys and proposed that the arithmetic product of Ti and carbon in percentages in the melt should follow Henry's Law if the morphology of TiC nucleus was spherical, i.e.

$$[\%Ti][\%C] \geq \text{Exp}\left[\frac{\Delta G^0_{TiC}}{RT} + \left(\frac{16\pi}{3}\frac{\sigma^3_{PL} V^2_m}{60KT}\right)^2 \frac{1}{RT}\right] \quad (1)$$

Where [%C] and [%Ti] are mass percentages of C and Ti, respectively, $V_m$ is the molar volume of TiC (in $m^3.mol^{-3}$), $\Delta G^0_{TiC}$ is the standard Gibbs energy (in $J.mol^{-1}$) for TiC, and K is Boltzman constant and $\sigma_{PL}$ is interfacial tension between TiC nucleus and the melt in $Nm^{-1}$. If the product of [%Ti][%C] in the melt satisfies the above relationship (1), stable nucleus will form and the nucleation of TiC will not stop until TiC concentration reaches equilibrium in the melt.

Jonsson et al. [**62**] worked on solidification of Fe- TiC composites. During the solidification TiC crystals nucleate below 1600 $^0$C grow continually as temperature drops. Jonsson has reported a ternary isothermal phase diagram of Fe-Ti-C composition. TiC continually grow along with ferrite dendrites at 1320 $^0$C, the liquid reacts with the ferrite dendrites which then partially or totally transform in to γ-dendrites. During further cooling, this transformation continues in the solid state and more γ, and TiC co-precipitate. At 1140 $^0$C austenite regions are finally transformed in to pearlite or martensite depending on the cooling rate. Final microstructure consists of dispersions of TiC particles in a matrix of pearlite or martensite. The formation of microstructure follows the Fe-Ti-C phase diagram as shown in Figure 8.

Kattamis etal **[50]** worked out basal projection of liquids surfaces of iron-rich corner as shown in Figure 9.

**Table – 1, Fe-TiC composite preparation by using various methods, structural details, properties determined and objectives**

| Sl No | Processing Method | Composite Particulates | Structural Details | Properties determined | objectives | Ref |
|---|---|---|---|---|---|---|
| 1. | Casting preparation by using In-Situ Synthesis method | Titanium Wires with the diameter of 0.7 mm were uniformly fixed at the bottom of the graphite crucible. The initial distance between wires was set as 2 mm. Then liquid cast iron was poured to the graphite crucible at above 1400 $^0$C and cooled to room temperature leading to formation of Ti-Fe composites | The SEM photo micro graph shows the presence of discrete TiC particles in Fe-TiC composites. The spherically and uniformly distribution of TiC produced by In-Situ in flight plasma process are confirmed by elemental mapping | Differential thermal analysis. | To Develop temperature resistance Material. | 1-2 |
| 2. | In-Situ by plasma smelting of ilmenite | Initially ilmenite and coke powder of required composition were thoroughly mixed and charged in hopper of the powder feeder. The mixture powder was directly charged into the molten mild steel. Argon gas was used as plasmogen gas and was passed through top electrode at the rate of 1 lt per minute. The arc was struck and the current of 350A was maintained with an arc voltage of about 60V. After ascertaining the complete melting of mild steel scrap, the mixture of ilumenite and coke powder was fed into crucible at rate of 50gm/min by suitably opening the screw of the powder feeder. After complete feeding of the smelting charge, the plasma arc was continued for 15-20 min to complete the reaction. | The composites which consists of a homogeneous dispersion of carbides in a matrix consisting of ferrite and a small quantity of perlite. | Wear | High and Low wear materials | 3-4, 5 |
| 3. | Powder Metallurgy | Stoichiometric iron-titanium carbide (Fe-Tic) powders were manufactured using combustion mode [SHS] and contained 70 Wt% titaniumcarbide. The processing of composition was performed in a solid state induction furnace master alloys were incorporated into the steel by directly pouring the powders onto the top of the molten steel and stirring with a ceramic impeller. The melt was held at 1600$^0$C for 20 min and after which furnace was switched off and composite allowed solidifying in the crucible. | The TiC particles are uniformly dispersed in the matrix. In addition, it can be observed that some rare TiC particles have formed. | Microstructure | To prepare corrosion resistance materials | 6,7 |
| 4. | In-Situ Exothermic Dispersion(XD) | The starting powders were Ti, Fe and Carbon Black. The powders were mixed in a composition of 28 wt% Ti ,7.2wt% C and 64.8 wt% Fe powders mixing was undertaken by planetary ball milling machine at 180 rpm for 24 hrs. After milling the powder was sintered in the 1380-1440 $^0$ C range in a vaccum furnace for 1 hr followed by furnace cooling. | The fine TiC particles are distributed around the atomized spherical tool steel powder | Corrosion resistant | Armour application | 9-11 |
| 5 | Cast-Sintering Technique | The composition of the melting point component and the carbide forming component of Cr-58.97%, Si-6.99%, V-3.06%, Mn-3.86%, Fe-27.12% powders were mixed in a ball mill for 24 hrs. and pressed into pellets using a steel pressure die. The pellets were bonded to the wall of casting mould. After baking at 433$^0$K was poured in the mould after solidification and cooling were done. | LAS and WCI consisted of martensite and some retained austenite. HAS contained martensite | Intrinsic Porosity | High Temperature Wear application | 21-22 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | Powder metallurgy by Hot Isostatic Pressing [HIP] | The powder of steel and TiC were mixed with matrix powder via ball illin. The mixtures of TiC and tool steel powders were canned in stainless steel at < 0.13 Pa vacuum before hot isostatic pressing process [HIP]. The encapsulations were HIP ped at 1250$^0$C and 120MPa for 4 hrs before furnace cooling | TiC grains varied between 0.8 to 0.9 indicating that the grains were nearly equi-axed. The area fraction of pearlite increasing carbon content of the composites. | Wear | To prepare temperature resistance material | **24-26** |
| 7 | Liquid-Phase sintering [LPS] powder sintering | The TiC hard phase was in the form of their XTiC™-powder, This powder contains 20% Fe, by weight, whilst the reminder is TiC which is present in the form of micron-sized particles. Thin powder was milled and sieved then mixed with carbonyl iron and graphite powder. Mixing was performed in a V-shaped blender for 120 minutes after mixing the powder was pressed in to a compact. | A homogeneous dispersion of carbides in a matrix consisting of ferrite and small quantity of Perlite. | Tensile and fracture analysis | High Temperature Wear application | **29-30** |
| 8 | Hot-isostatic pressing [HIP] powder metallurgy | Three different powders were used to form the composites low alloy steel [LAS] high alloy steel [HAS] and white cast iron [WCI]. In a first series 10 % volume of FeTi particles were dispersed in each matrix powder and graphite was added in stoichiometric proportion of TiC accounting to 0.25 times the Ti mass of FeTi. No graphite was added to HAS and WCI because the matrix powders of high carbon content were used as carbon donors for thr formation of TiC. Mixture is statically pressed at 1125$^0$c and 105MPa for 4 hrs. | LAS and WCI consisted of martensite and some retained austenite. HAS contained martensite. | Wear | High Temperature Wear application | **38-39** |
| 9 | In-Situ technique | Fe-TiC composites were produced by reacting Fe-C molten alloy with 4, 8, 12 and 16 weight percentage of titanium. The charge material used was clean steel scrap and petroleum coke. petroleum coke was added to adjust the carbon content. High temperature refractory crucible was used as a protective layer to produce TiC reinforced steel composites. | TiC grains varied between 0.8 to 0.9 indicating that grains were nearly equi-axed. The area fraction of perlite increased with increasing carbon content of the composites. | Tensile and Fracture analysis | To Prepare temperature materials. | **40-41** |
| **10** | Powder metallurgy [SHS] self-propagating high temperature synthesis. | Iron-Titanium carbide (Fe-TiC) additive powder was manufactured using combustion mode. SHS and contained 70% titanium carbide. | The fine TiC Particles are distributed around the atomized spherical tool steel powder. | Corrosion Resistant | Prepare Corrosion Resistant materials. | **42-43** |

**Table 2.Reactants and volume fraction of Fe-TiC based alloy matrices**

| Sl.No. | Reactants | Generated reinforcement | Volume fraction of Dispersion | Reference |
|---|---|---|---|---|
| 1. | The raw materials of cast-Iron and titanium wire and graphite crucible | TiC | 2 to 5% TiC | 1-2 |
| 2. | Powders of Fe, Ti and carbon blank composition of 28wt.%Ti 7.2wt.%C and 64.8wt%Fe | TiC | N/A | 9-11 |
| 3. | Powder of ferrotitanium(Ti,Fe) and carbon | TiC | 0.1 to 0.5 TIC | 27-28 |
| 4. | 1. Coal added to Fe-5.2 wt% Ti melt<br>2. 4g addition to 33g of Fe 24wt% Ti melt<br>3. Ti Filings added to Fe-C melt | TiC | >0.4 TiC | 31-33 |
| 5. | TiC powder addition to pure iron and high carbon iron melts | TiC | N/A | |
| 6. | 1. Low Alloy Steel + FeTi and graphite<br>2. High Alloy Steel + Fe Ti and graphite<br>3. White cast Iron + Fe Ti and graphite | TiC | 10 to 20 μm | 34-35 |
| 7. | Iron- Titanium carbide[Fe-TiC] additive powders | TiC | >5% of TiC | 40 |
| 8. | Reacting Fe-C molten alloy with titanium | TiC | 6 to 22% of TiC | 54 |
| 9. | Fe Ti added to ductile iron melt | TiC | Up to 0.30 TiC | 64 |

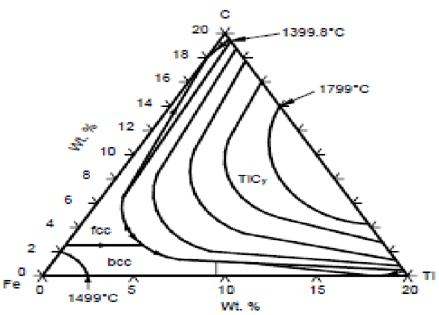


**Figure 8. Indicates, calculated liquid projection with isotherm for the iron-Rich region [14]**

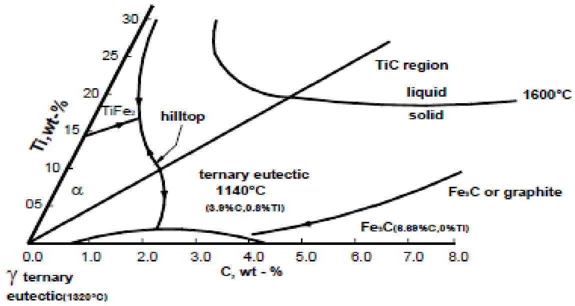


**Figure 9. Iron Rich corner of the Fe-Ti-C phase diagram showing the Basal projection of liquidus surfaces [48]**

## 4. MECHANICAL PROPERTIES

Titanium carbide is a covalently bonded material which can disperse uniformly in a steel matrix on account of its easy availability, high hardness, high melting point and good thermodynamic stability. Variety of titanium carbide reinforced steel composites are currently being investigated because of the possibility of utilizing cost- effective processing techniques to produce materials which have good combination strength, ductility and fracture toughness.

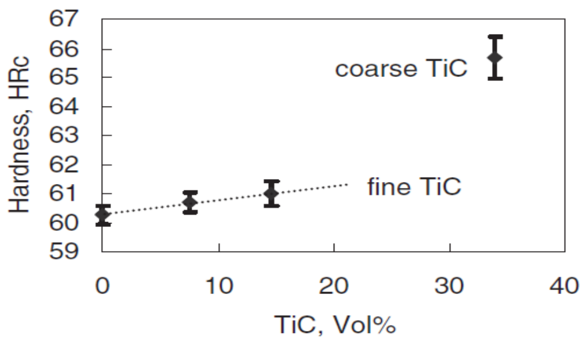


**Figure 10. Shows increase of hardness with TiC volume fraction [24]**

### 4.1 Hardness

Jhewn-Kuang Chen **[24-26],** studied the hardness of the composites, and observed that the micro hardness is increase with the percentage of TiC addition. The plot shown in figure 10, hardness separates into two classes by fine and coarse TiC ( for corse TIC where is the graph). In composition hardened by fine TiC particles (5 and 10 mass% or 7.5 and 14.6 vol% TiC), their hardness indeed increase linearly with TiC volume fraction. The composites hardened by coarse TiC particles (25 mass% or 34 vol% TiC) shows much higher hardening effects to the composites then the fine TiC particles. Terry and chinyamakobvu [**4-5**] have reported that hardness increases with increasing volume percentage of TiC. The hardness increased from 380 HV10 to 483 HV10 with the volume fraction of TiC varying from 3 to 11.8 percent.

Dogan et al [**63**] have conducted hardness test on 0.4 volume fraction of TiC reinforced steel with varying carbon percentage. They found that hardness varies from 54 HRC to 71 HRC with carbon content varying from 0.34 to 2.66 % with keeping TiC content constant.

### 4.2 Flexural strength

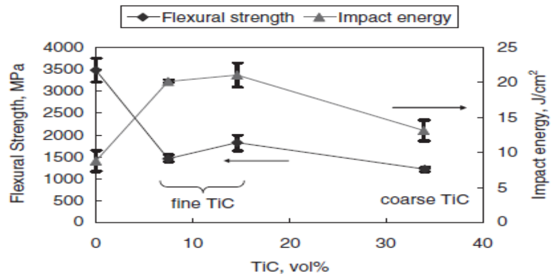


**Figure 11. Changes of flexural strength and impact energy with TiC volume fraction [24]**

The flexural strength drops without TiC addition and with addition as shown in fig 10. The drop in flexural strength indicates changes in fracture modes when TiC is added. Jhewn-Kuangchen et al. **[24-26]** worked on flexural strength for samples of difference in the amount of TiC addition 5, 10, and 25 mass % TiC. The difference of flexural strength in 5, 10 and 25mass% TiC samples is rather small. This indicates that once the fracture tips are initiated, the fracture propagation is relatively easy in passing TiC particles, or the flexural strength is controlled by crack initiation process, and the amount of TiC does not affect the flexural strength greatly in TiC containing composites.

### 4.3 Impact energy of Fe-TiC composites.

The impact energies increase with TiC for 5 and 10 mass% specimens but drops for 25 mass% TiC specimens as shown in figure 11. It is observed from the figure 11, the impact energies of all samples are lower than 22J/cm$^3$. The low impact energies indicate brittle fracture characteristics for all materials currently studied. The higher impact energies of 5 and 10 mass% TiC specimens than non-TiC-added steel indicate that fine Tic particles have very different effects on hardness and flexural strength **[24-26].**

J K Chen et al.**[24-26]** studied on crack propagation. They reported crack propagation areas across TiC particles increases, when TiC particle size decreases. The total crack propagation area across TiC particles is inversely proportional to the size of TiC particles. It is observed that in the figure 11, the 5 and 10 mass% fine TiC containing samples can thus bear higher impact energies than 0 and 25 mass% TiC added materials due to increase of resistance for crack propagation.

### 4.4 Tensile Strength of Fe-TiC composites.

Generally increasing the volume fraction of reinforcements increases the strength of the composites [**60**]. Intuitively, finer strengthening particles give rise to larger strengthening effects. This interpretation is based upon the assumption that the particles are dispersed uniformly in reducing spacing **[24-26].** Parashivamurthy et al. **[40-41]** worked on tensile properties of Fe-TiC composites, according to ASTM E8 M-93 prepared specimens the young's modulus is reduced when volume fraction of TiC is increased. The variation of young's modulus with volume fraction of TiC as shown in figure 12. Similarly ultimate tensile strength is also reduced when volume fraction of TiC is increased the variation of ultimate tensile strength with volume fraction TiC as shown in figure 13. Elongation is also reduced from 18.21 (volume fraction of TiC 0%) to 0.02 percent (in volume fraction of TiC 21%) indicating the increased brittleness

Galagali et al.[**7**] have produced composites with varying contents of titanium carbide by reaction method. They reported that a significant increase in the ultimate tensile strength of composites. It increased from 363 Mpa to 775 Mpa with increasing TiC in the matrix. Yangshan sun et.al. **[44-45]** worked on tensile test on heat treated specimens of low carbon and medium carbon steels reinforced with TiC. They reported, addition of TiC caused increase of both Yield and ultimate strength but slight increase of ductility.

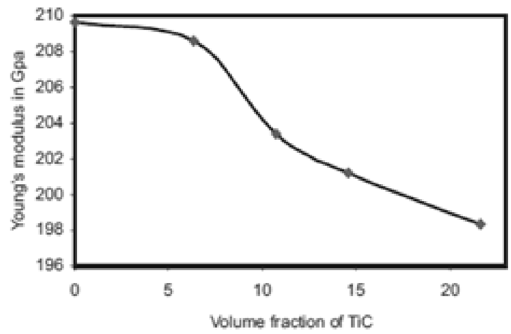


**Figure 11. Variation of Young's modulus with volume of TiC [40]**

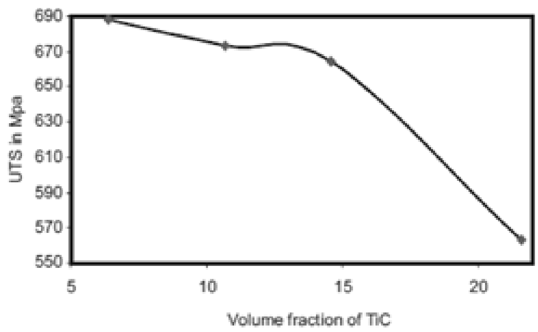


**Figure 12. Variation of tensile strength Fraction with volume fraction of TiC [40]**

## 5. WEAR PROPERTIES OF Fe-TiC COMPOSITES.

Wear as a general phenomenon remains somewhat unpredictable in quantitative terms. Metallic wear is a complex event and includes such complicating factors as work hardening, oxidation of exposed metal, metal transfer and phase changes in metallurgical composition.

The seven distinct mechanisms for the removal of material from sliding metal surfaces are
(a) Continuous wear (b) Galling (c) Pitting (d) Abrasion (e) Chemical corrosion (f) Fretting corrosion (g) Surface flow

Qian Lin Wu et al. **[44-45]** studied the differences of the wear properties between the matrix steels and their corresponding TiC strengthened steels. They reported that TiC addition to the common straight steels resulted significant improvement on wear resistance. C.C Degnan et al. **[42-43]** worked on dry sliding wear behavior of the composite material, and its unreinforced counterpart was investigated at room temperature 250 $^0$C and 500 $^0$C against a white cast iron counter face. The test specimen was 5wt% TiC- steel composites when a test temperature of 250$^0$C was employed; The TiC- reinforced composite exhibited low rates of wear over the increasing loading. When a temperature of 500$^0$C was used, both the composite and unreinforced steel pins exhibited negligible reduction in length or mass loss over the full range of loading.

P.H. Shipway et al.**[6-7]** Conducted a reciprocating sliding wear behavior of steel based titanium carbide reinforced metal matrix composites. They reported, at the lowest level of loading, the TiC reinforced steel shows the significant improvements in wear resistance over its unreinforced counterpart. Many workers in this field have observed similar improvements and proposed various mechanisms to explain this behavior.

Shiyao Qu et al. **[23]** worked on TiC particles reinforced composite coating and the substrate. They reported the composite coating has high wear resistance compared to substrate. The increased wear resistance of the composite coating is mainly attributed to the reinforcement of TiC carbides. Hans Berns et al. **[38-39]** developed an abrasion resistant steel composite with in-situ particles by hot isostatic pressing (HIP). Hans developed two types of specimens namely Low alloy steel [LAS] reinforced with TiC and High Alloy Steel [HAS] reinforced with TiC up to 50% volume fraction. They reported that the wear resistance of the HAS metal matrix is higher than that of LAS with 10 vol% of TiC.

## 4. APPLICATION OF Fe-TiC COMPOSITES

Many applications have been identified for the Fe-TiC composites. These include, to develop temperature resistance material, Armour applications **[29-30].** Also steel reinforced TiC- Ferrous matrix composites have applications in industry such as paving, coal handling, mining and power station etc.**[28-39]** This composites is also developed for corrosion resistance material**[24-26]**. Benefits can be extended to other industries such as in waste- derived fuel plants, mould inserts and mould gates in plastic industries, in hot working industry this composites is used for guide, rollers, worm handling punches and extrusion dies. This composition is also used to make rot orthers and pressure plates for fuel pumps, and where problems as excessive wear of pneumatic pipes and duck work, and shredding and milling components **[60].** TiC reinforced composites in high technology applications is attractive primarily because of many exceptionally good and temperature resistance, wear resistance and corrosion properties **[64]**.

## CONCLUDING REMARKS

The present article provides an overview of the various synthesis routs of FE-TIC composites, which has been evolving over the years. A variety of techniques have been developed for the processing of FE-TIC composites, the available literature shows that the processing techniques can classified as Powder metallurgy, liquid metal particulate mixing and In-Situ production. Many research groups to produce in-situ FE-TIC composites with uniform dispersion of TIC reinforcement. Advantages and disadvantages of these routs have been examined and commented upon. The review has shown that the interface between particles and matrix contributes to the enhancement of hardness, elastic modulus, and yield strength and wear resistance.

This review also reveals that the microstructure of FE-TIC composites exhibits that TiC particles are homogeneous and uniformly distributed into the matrix. It has also been found that a phenomenal improvement in wear resistance occurs owing to the incorporation of TiC particles in a Fe matrix.

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