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TENSILE FRACTURE BEHAVIOR OF FE-CR-TIC COMPOSITES

Srinivasa K[*1] & Dr. K I Parashivamurthy[2]

[*1]Associate Professor, Department of Mechanical Engineering, ATME College of Engineering, Mysore, India.

[2]Professor, Department of Mechanical Engineering, Govt. College of Engineering, Chamarajanagara, India.

ABSTRACT

Ferrous matrix composites materials containing titanium carbide are produced by the direct reaction of pure titanium with molten Fe-Cr-C alloy. TiC particles were formed in liquid iron solution by the reaction between pure titanium and carbon available in molten Fe-Cr-C. The microstructure, tensile behavior and fracture characteristics of Fe-Cr-TiC composites are discussed. Examination of the composite microstructure revealed a near uniform distribution of the particulate reinforcement through the metal matrix. Both the elastic modulus and tensile strength of the composites are slightly lower than that of the non- reinforced matrix. The fracture surface analysis at ambient temperature reveals that fracture mode is ductile at low volume fracture of TiC and it becomes brittle as the volume fraction increases. Fractograph analysis of the tensile fracture surface revealed an overall brittle appearance at the microscopic level.

KeyWords: *Titanium carbide, In-situ, tensile fracture, Fractography*

I. INTRODUCTION

Ferrous based metal matrix composites [MMC's] have attracted the considerable attention of researches in the field of material science in recent years as they possess potential improved properties over commercial metals and alloys. In recent years, particle reinforced iron matrix composites have been a core of attention within the range of new materials **[1-2]**. Based on earlier investigations, incorporation of ceramic particles i.e. Al_2O_3, SiC, TiB_2, WC and TiC in an iron metal matrix give great improvement on the mechanical and wear properties of iron and its alloys. Among these ceramic particles, TiC had drawn much attention as reinforcements in iron matrix due to its high hardness, wear resistance, high chemical stability, high thermal and shock resistance**.[3]** Iron based composites with reinforcement of TiC particles have received interest in these classes of materials. **[4-5]** although, most of the work on iron based composites are centred on low and medium carbon steel to improve upon their wear resistance, strength and stiffness of the composites.

TiC particles with high hardness are widely used as the reinforcing phase for iron matrix due to good wettability with liquid iron **[6].** The TiC phase strongly influences the mechanical, wear and corrosion properties by bonding with matrix of iron **[7].** Bandyopadyay and Das synthesis the TiC reinforced ferrous based composites for wear resistance application [5]. The ferrous matrix prepared is having high wear resistance but, high brittleness. Prarashivamurthy et al **[8]** also developed TiC reinforced composites by In-Situ technique and observed in improved wear and erosion properties along with reduced tensile properties. But, in many industrial applications, ferrous matrix composites essential to provide combination of wear properties with toughness gives high service life of the components **[9]**. The various alloying elements like Ni, Cr, Mn etc. enhances the properties in the matrix of iron. The alloying elements like chromium, up to 12% increase toughness and wear resistance of the steel **[10]**.

In-situ casting method for synthesizing the TiC crystals in the molten iron is observed by reacting titanium along with carbon in molten iron. TiC precipitation is based on the thermodynamically first order of kinetic reaction **[12-13]**. The synthesizing the TiC particles in Fe-Cr molten alloy Cr promote the formation of TiC along with toughened matrix austenite face **[14-16]**. Not much of literature is available for understanding fracture behavior of Fe-Cr-TiC composite.

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The present study was undertaken with the primary objective of influence of TiC on fracture behavior of Fe-Cr-TiC composite produced by casting method

II. EXPERIMENTAL PROCEDURE

The induction furnace of 20kg capacity was used to melt the alloy. The charge material used was clean steel scrap, Chromium13% and petroleum coke. Petroleum coke was used to adjust the carbon content, and 3.5, 7, 10.5 and 14 weight percent of titanium were added respectively. High temperature refractory crucible was used as the reaction container. The crucible was heated via water-cooled copper coils in an induction furnace. The reaction time and temperature are 15 minutes and 1620^{o}C respectively. For TiC formation, a calculated weight of titanium bar was plunged in to the liquid Fe-Cr melt to form titanium carbide. After completion of reaction, the power was turned off and melt was poured into sand mould and allowed to solidify. The chemical composition of the base metal was determined using vacuum emission spectrometer, carbon content in the sample were analyzed by wet method and composition of the alloy is tabulated as shown in table 1. The microstructure of composites was examined using optical microscope and scanning electron microscope (SEM). The castings are designated as 1, 2, 3 and 4 for reference based on the volume fraction of TiC in each of them

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III. MICROSTRUCTURE

Four different grades of Fe-Cr-TiC composites were prepared as described in section 2. Table 1 gives the chemical composition of the Fe-Cr-TiC composites. The castings are designated 1, 2, 3, 4 and 5 for future reference based on the volume fraction of TiC in each of them.

Typical microstructures of Fe-Cr-TiC composites in as-cast condition are shown in figure 1 to 4 at two magnification of 100X and 400X for sample 3and 5. The structure shows the carbide distribution in the matrix with well defined grain boundary. The size of the carbide increases with increasing carbon and titanium contents.

The aspect ratio of the Fe-Cr-TiC composites between 0.92 to 0.94 shows (Table 2) the crystals are nearly equiaxed. The structure shows pearlite in the matrix. The bonding between TiC and Fe-Cr matrix is good.

The Fe-Cr-TiC composites were examined in the SEM. Typical high magnification micrographs of sample 3 and 5 are shown in fig 5 and 6. The structure shows that the TiC particles are nearly rectangular in shape with occasional coalescence of a few carbides.

Energy dispersive X-ray analysis was carried out on all the composites. The figs 9, 10 and 11 show the X-ray mapping of Chromium, Titanium, and iron respectively. From the X-ray mapping, it is clear that no chromium is uniformly distributed in the matrix. The X-ray profile data of the Fe-Cr-TiC matrix (Fig 12) shows that 14.87 Chromium is dissolved in the matrix of steel for sample no 4 which is in comparable in with the chemical analysis data.

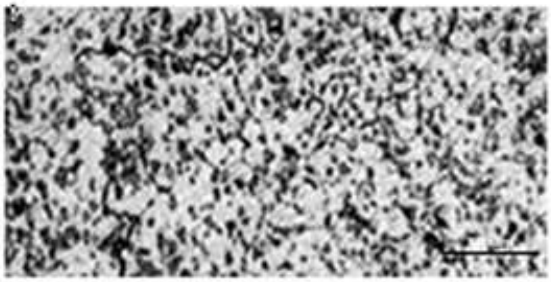

Fig 1: Optical microstructure of sample 3 with lower Magnification (100X).

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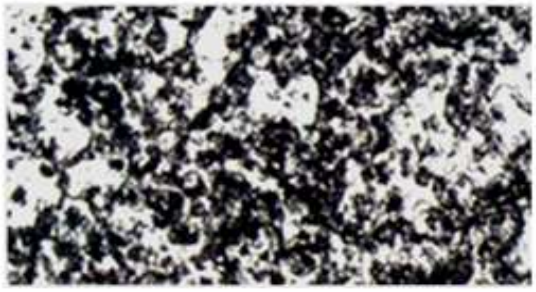

Fig 2: Optical microstructure of sample 3 with higher Magnification (400X).

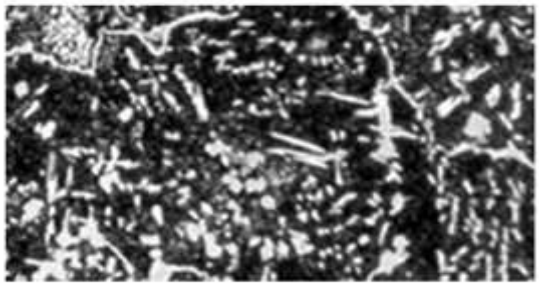

Fig 3: Optical microstructure of sample 5 with lower Magnification (100X).

Fig 4: Optical microstructure of sample 5 with higher Magnification (400X).

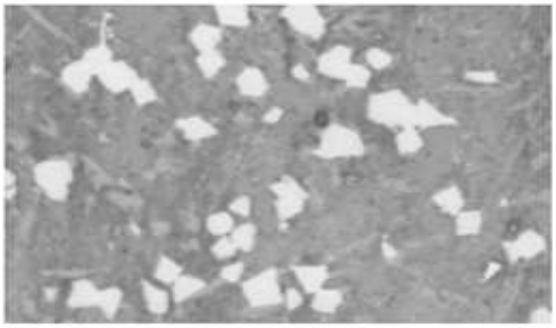

Fig 5: Scanned electron micrograph of Sample 3 with a lower magnification.

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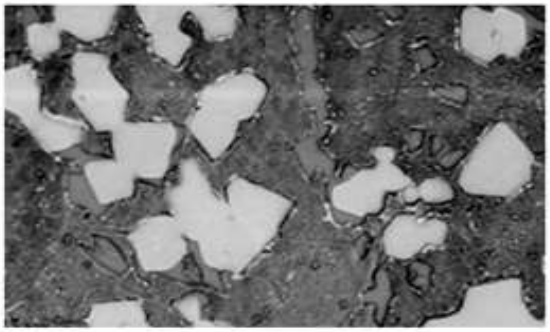

Fig 6: Scanned electron micrograph of Sample 3 with a higher magnification.

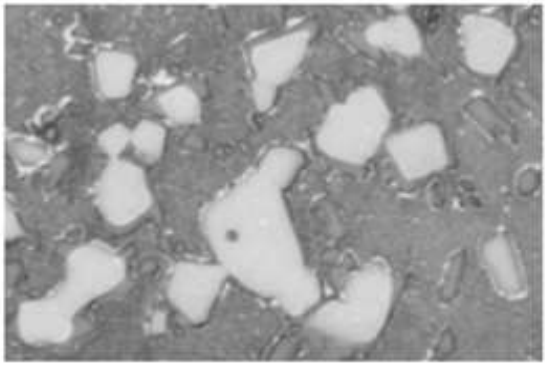

Fig 7: Scanned electron micrograph of Sample 5 with a lower magnification.

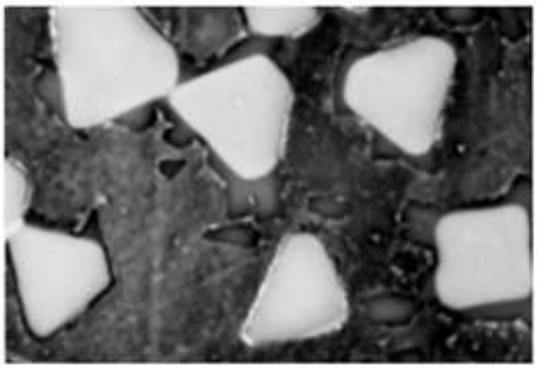

Fig 8: Scanned electron micrograph of Sample 5 with a higher magnification.

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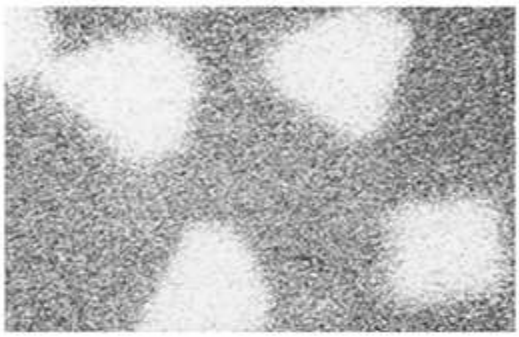

Fig 9: X-ray mapping of Chromium

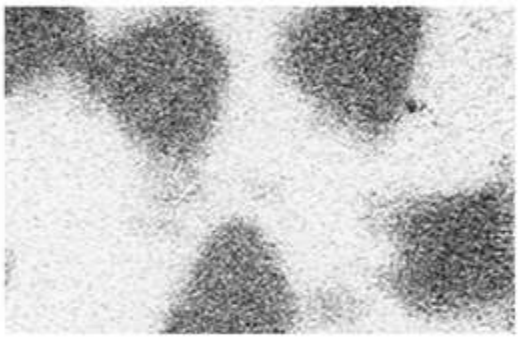

Fig 10: X-ray mapping of Titanium

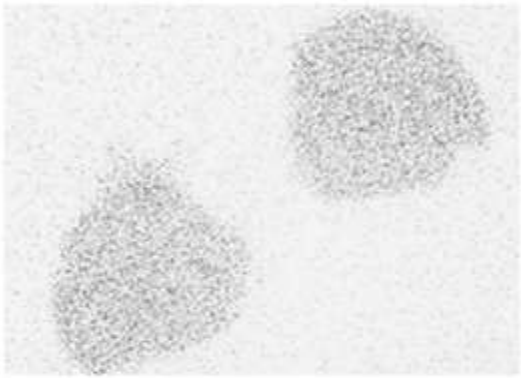

Fig 11: X-ray mapping of iron

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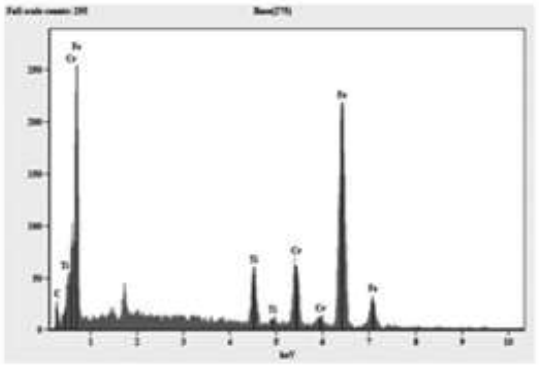

Fig 12: Shows X-ray diffractogram of Sample

Table 1. Chemical analysis of Fe-Cr-TiC composites in (wt %)

Sample no	C	Mn	Ni	Cr	Ti	Fe
1	0.83	0.66	0.11	13.58	0.036	Balance
2	0.85	0.52	0.94	12.58	3.99	Balance
3	1.37	0.56	0.00	12.48	7.56	Balance
4	1.63	0.73	0.00	12.36	10.36	Balance
5	2.14	0.36	0.00	12.24	14.51	Balance

Table 2: TiC grain size measurement of Fe-Cr-TiC composites

Sample no	Minimum grain size in µm	Maximum grain size in µm	Mean grain size in µm	Aspect ratio (H/W)	% of pearlite Area	Volume Fraction of TiC
2	13.1	17.0	15.0	0.92	2.3	4.62
3	15.6	19.8	17.7	0.94	2.6	8.26
4	21.3	23.9	22.6	0.94	4.5	12.67
5	23.3	26.2	24.5	0.94	4.8	14.87

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Table 3: Rockwell hardness and micro hardness data

Sample no	Rockwell hardness in Rc	Micro hardness HV-30
1	40.9	316
2	42.5	825
3	43.9	920
4	45.2	970
5	47.8	1020

IV. HARDNESS

The Rockwell hardness of all the samples were measured using hardness testing machine at a test load of 1471 N and a diamond cone indenter. Rockwell-C hardness values are reported by taking the average of five readings. Micro hardness increases drastically with increasing amount of carbide as shown in Table 3. Fig 13 shows that Rockwell-C hardness increases with increasing volume fraction of carbide.

V. TENSILE TEST

The specimens of cross-sectional area of 8mmX6mm and gauge length of 60.2 mm were used for tensile rectangular test specimen were cut with rubber abrasive wheel and ground according to ASTME standards, uniaxial tests were performed up to failure on a fully automated servo hydraulic mechanical test machine equipped with a 50KN load cell. The modulus of elasticity was evaluated using the strain control mode. The specimens were deformed at a constant strain rate of 10-3/sec. The tensile properties were measured and the results for Fe-Cr-TiC composites are given in table 4. Fig 17 and 18 show scanning electron fractograph of tensile fracture specimens of the composites of sample 3 and 5. Sample 3 shows little ductile fracture, where as sample 5 shows brittle fracture.

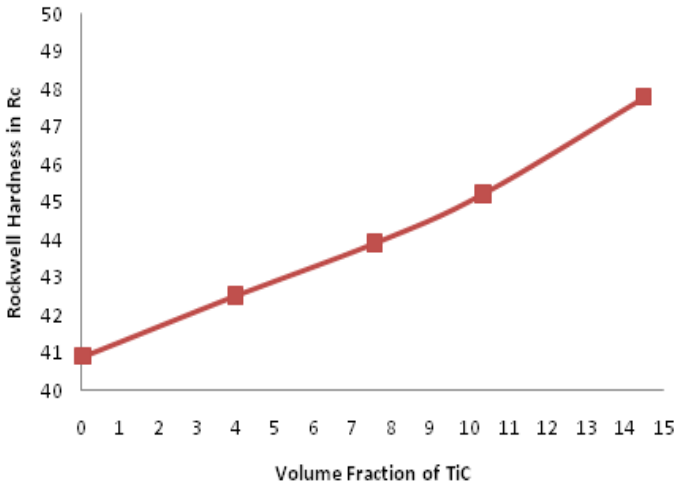

Fig 13: Rockwell-C Hardness v/s Volume fraction of TiC

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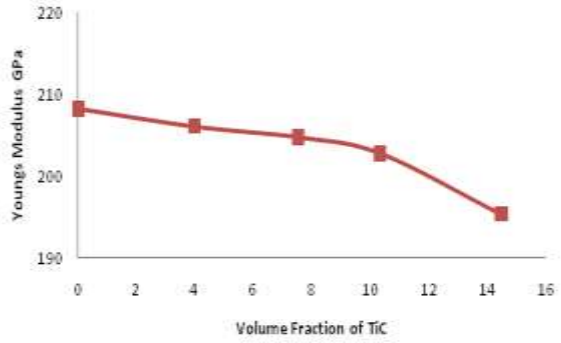

Fig 14: Young's Modulus v/s Volume fraction of TiC

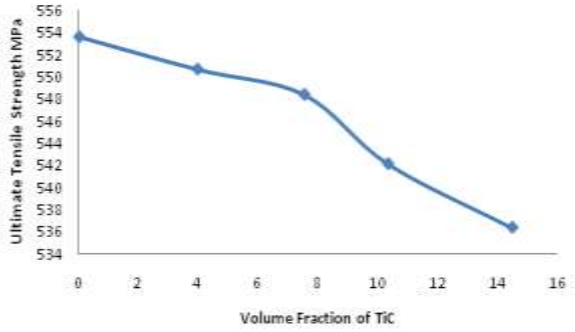

Fig 15: Ultimate Tensile Strength v/s Volume fraction of TiC

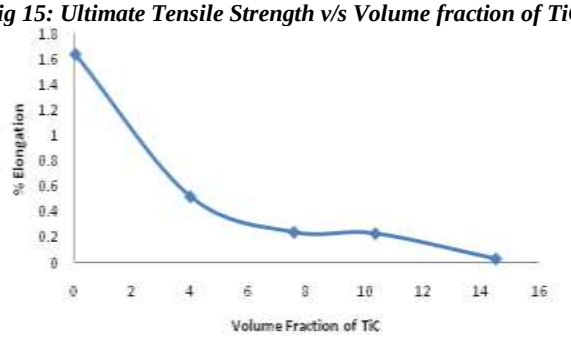

Fig 16: % Elongation v/s Volume fraction of TiC

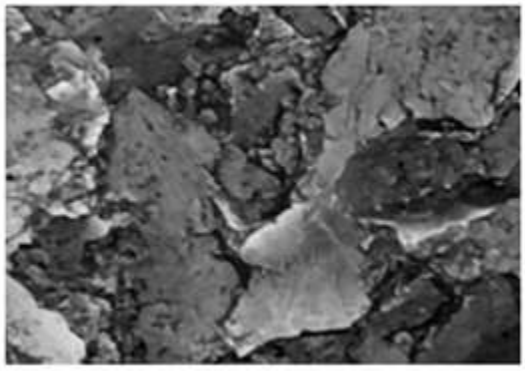

Fig 17: Fractograph from tensile sample 3

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Table 4: Tensile properties of Fe-Cr-TiC samples

Sample no	Young's modulus in GPA	Tensile strength in MPA	Percentage elongation
1	208.14	553.61	1.64
2	206.11	550.68	0.52
3	204.68	548.39	0.24
4	202.69	542.36	0.23
5	195.3	536.36	0.03

VI. CONCLUSION

Based on the result of this investigation on the fracture behavior of TiC reinforced with Fe-Cr matrix, the following observations were made;

- Direct addition of pure titanium rod under protective cover of lime holds good promise for producing Fe-Cr-TiC composites.
- The size, shape and distribution of TiC are mainly dependent on the titanium and carbon content in the matrix. High titanium and carbon contents lead to large TiC size in composites.
- With increased volume fraction of TiC, Reduction in Young's modulus and ultimate tensile strength.
- Percentage elongation is also drastically reduced with increasing volume fraction of TiC.
- Fractography of the deformed samples revealed microscopically a brittle appearance due to particle cracking.

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