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Hardness and Wear Improvement of Fe-Mn-TiC Composites Produced by in-Situ Method

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Abstract— **Metal Matrix Composites (MMCs) have been extensively used in various industries because of their beneficial properties over commercial metals and alloys. Ferrous based composites containing carbides, nitrides and borides with large volume percent of reinforcement are favored for abrasion resistance. Titanium Carbide (TiC), the hardest refractory carbide helps in abrasion resistance in the matrix of steel based composites. TiC precipitates by the reaction of titanium with carbon in the matrix of steel which improves wear and mechanical properties. Form last two decade, attempts to produce TiC reinforced steel composites have intensified. Further, addition of Mn in the Fe-TiC composite improves the mechanical properties of the composite.**

Keywords—Composite; Metal Matrix; Titanium carbide; Wear; In-Situ Precipitation; Manganese; Steels.

I. INTRODUCTION

From last two decades, production of TiC-reinforced steel matrix composites by casting route gains significant research interest due to their wide varieties of properties compared to monolithic counterpart. In early 1970s, TiC reinforced steel composite have been prepared for high strength and wear resistance at elevated temperature applications [1]. The reaction of titanium in molten Fe-C is one of the simplest technologies for production of TiC reinforced steel composite through solidification process. Many investigators [2–6] have studied the mechanisms of reaction and precipitation kinetics of TiC in molten steel. Fundamental study on solidification of Fe-TiC composites was conducted by Jayashankar et al. [2] with the aim of developing Fe-TiC composite by plasma smelting of ilmenite. Jing Wang et al. [4] have conducted experiments on the precipitation of TiC by reacting pure titanium in liquid Iron-Carbon. Parashivamurthy et al. [6] have produced Fe-TiC composites by reacting titanium in molten Iron-Carbon alloy. These composites produced by casting technique suffer from ductility due to the precipitated TiC crystals. This may limit the use of these composites in industries where, strength, toughness and wear properties are important. Manganese is one of the major alloying elements with steel and it contributes markedly to the strength and hardness and is most effective in medium and high carbon steels [7]. This element has a moderate effect on hardenability and increases the ductility in the steel matrix. It lowers the critical cooling range in low and medium carbon steel. Similarly, Ti is another alloying element in steel which improves hardness and wear resistance in medium and high carbon steel. These two elements have the tendencies to form carbides in steel matrix out of which titanium has greater tendency compared to manganese. In the absence of carbon, these elements dissolve to a certain degree in ferrite phase [8, 9]. The present study was undertaken to know TiC precipitation in the molten Fe-Mn-C alloy with 5% manganeseand varying titanium from 1% to 4% in the steps of 1%. The effect of manganese on the size and shape of the TiC along with hardness of the precipitated TiC in Fe-Mn matrix was characterized with pin on disk wear testing.

II. MATERIALS AND METHODS

For developing Fe-Mn-TiC composites, 3.75 kg of low carbon steel was charged into a water-cooled alternating current solenoid coil induction furnace of 10 kg capacity. After melting, the dross was skimmed off and 250 grams of ferro- manganese alloy, having an 80% of yield, was added to the low carbon molten steel and melting/superheating carried out to maintain the liquid metal temperature at 1600 ±50 ºC. For increasing required carbon in molten steel, pure petroleum coke powder was added. After confirming the dissolution of coke powder, the dross was skimmed and molten metal was covered with lime powder about 20 mm thick. Further, pure titanium rod was plunged through the lime powder and allowed to react with carbon available in molten metal. The reaction time was 10 minutes. The melt was transferred to ladle which was pre heated to about 1000 º C and from the ladle, the molten metal was poured into CO_2 sand mould.

Four specimens were casted along with carbon varying from 1 to 4 weight percentages in steps of 1 percentage and titanium varying from 4 to 16 weight percent in steps of 4 percent, to get four different compositions of Fe-Mn-TiC castings.

The chemical analysis of composites was identified by using Wavelength Dispersive Spectroscopy (WDS) at the operating voltage 10kV and beams current 10^{-6} amperes. The contentsof in the composite samples were determined by wet method. The microstructures of the Fe-Mn-TiC composites were observed using an OPTIKA B-500 Ti 2F and SEM (Hitachi S- 3400N) connected to Energy Dispersive X-ray analysis equipments (EDX). Under the SEM analysis, for surface imaging secondary electron detector was used and a backscattered electron detector was used for compositional based imaging.

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III. RESULTS

Table 1 gives chemical analysis of Fe-Mn-TiC composites. The base metal is named as A. It contains 5 weight percent manganese and 0.70 percent carbon. The Fe-Mn-TiC composites are named as A1, A2, A3 & A4 by varying titanium and carbon respectively.

Table 1. Chemical Analysis of Fe-Mn-TiC Composites (in weight Percentage)

Sample No.	C	Cr	Mn	Ti	Fe
A	0.70	0.12	5.03	0.30	Balance
A1	0.90	0.11	4.10	4.25	Balance
A2	1.85	0.10	5.15	7.73	Balance
A3	2.57	0.12	5.37	10.35	Balance
A4	3.88	0.15	5.49	15.79	Balance

The typical microstructural analysis of Fe-Mn-TiC composites of sample A3 is shown in the Figure 1. TiC particles precipitated in the matrix of Fe-Mn and no precipitated manganese carbide seen. Similarly Figure 2 shows SEM microstructure of Fe-Mn-TiC of sample A3 which indicates uniform distribution of TiC in the matrix of Fe-Mn alloy.

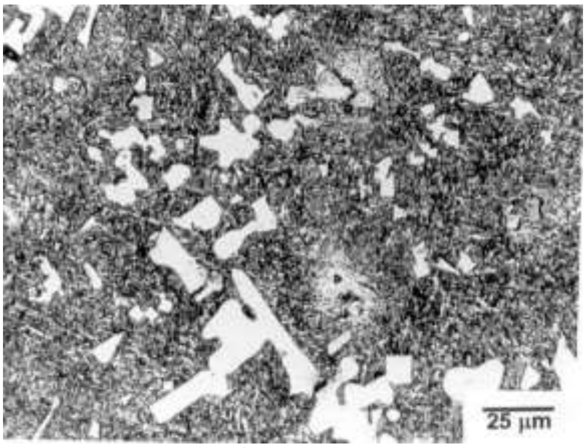

Fig. 1. Optical microstructure of the in-situ precipitated TiC in the matrix of Fe-Mn alloy for the sample A3.

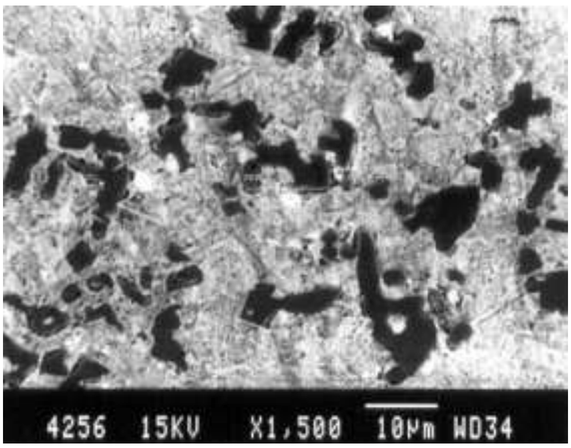

Fig. 2. SEM microstructure of the in-situ precipitated TiC in the matrix of Fe-Mn alloy for the sample A3.

The Rockwell hardness of both alloy as well as the composite castings were measured using INSTRON WOLPERT make

comprehensive hardness testing machine at a test load of 1471 N with a diamond cone indenter. With an average of five readings Rockwell-C hardness values are reported.
The measurements for micro hardness were made on different TiC carbide particles in the composite castings using Mitutoyo HM-200 make micro hardness tester at a test load of 0.2943 N and average of five different readings is computed. The micro hardness is taken on all the various phases present in the structure.
The below Table 2 shows the Rockwell-C scale and micro hardness for Fe-Mn-TiC composites. Rockwell and micro hardness increases with increasing volume percent of TiC in Fe-Mn-TiC composites.

Table 2. Micro Hardness & Rockwell Hardness Data

Sl. No.	Micro hardness HV 30	Rockwell Hardness in HRc
A	300	45.2
A1	543	46.2
A2	579	48.9
A3	615	51.5
A4	821	53.1

Using pin-on-disc apparatus the adhesive wear phenomenon for all the specimens were studied. A cast iron disc of hardness of 54 HRc was used for wear resistance evaluation. The specimens were ground by means of grit emery paper of cross section 5mmX5mm, and all the specimens were accurately weighed up to 0.001 decimal points and placed on the grip to hold the specimen. The test was conducted an indication by load cell i.e frictional force was noted. After finishing point of the test, the specimen was carefully cleaned that is burrs at the edges were detached and specimens weighed again precisely. By applying weight loss method, the wear rates were calculated. The tests were conducted under varying loads (5N to 85N at 200 rpm for 15 min), varying sliding distance 500m, 1000m, 1500m, and 2000m at load of 50N) and sliding velocity of 3.33m/s. Figure 3 and 4 shows the variation of weight loss with load and sliding distance for the samples A to A4 and also shows that with increasing Rockwell-C hardness and with increase in volume fraction of TiC, wear resistance increases.

Figure 5 and 6 shows that the scanning electron micrograph ofpin on disk wear surface. Specimen A shows mild surface during the pin on disk abrasion whereas sample A4 shows hard surface during pin on disk wear of sample A4.

IV. DISCUSSION

In the present work, TiC reinforced composites are prepared by reacting titanium with carbon in Fe-Mn-C molten alloy. The TiC formed quite rapidly, in a short time as 10 minutes at 1650ºC. The Manganese is fixed at approximately 5%, Carboncontent varies from 1 to 4 weight percentage in steps of 1 percentage and titanium in varied from 4 to 16 weight percentage in steps of 4 percentages.

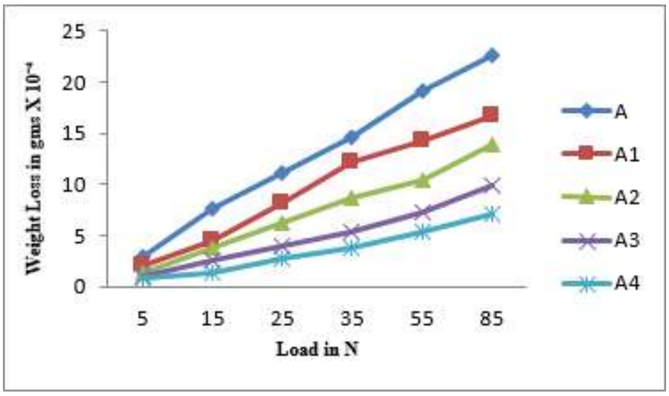

Fig. 3. Weight loss v/s load

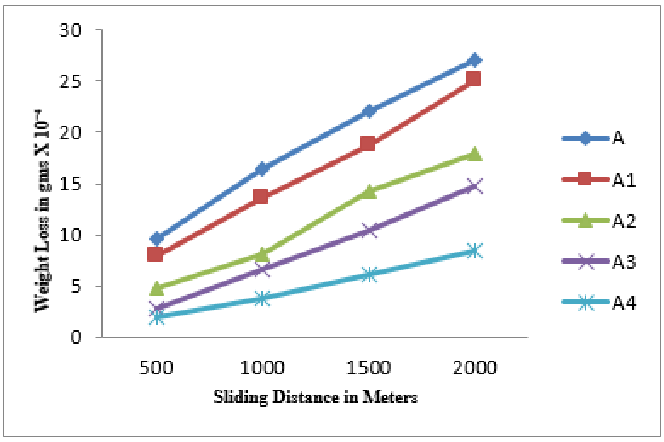

Fig. 4. Weight loss v/s Sliding distance

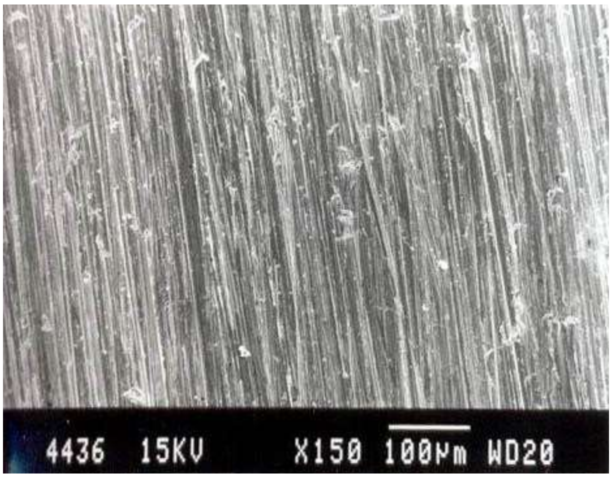

Fig. 5. SEM image of pin on disk wear surface for the sample A.

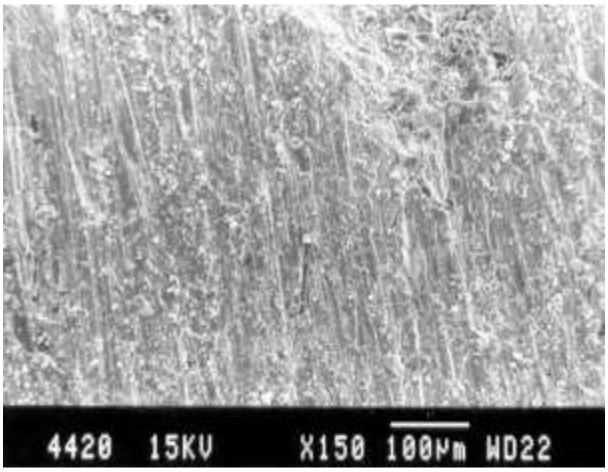

Fig. 6. SEM image of pin on disk wear surface for the sample A4.

During solidification, Fe-Mn alloy solidifies partly as δ-solid solution, partly as γ-solid solution, and Mn C. In molten metal manganese reacts with carbon and converted into MnC at below 1,450°C. The δ-solid solution formed at solidification changes to γ in the range of temperature just below the solidus (approximately 1,400°C). Final crystal structure for the 5% manganese and 0.85% carbon at room temperature is ferrite, pearlite and MnC [8]. As solidification progresses, manganese in the matrix lowers the carbon content of the eutectoid. In the iron carbon and manganese system, the element manganese is weak carbide former. Manganese lowers the critical cooling range and lowers the carbon content of the eutectoid.

The optical and SEM structures of Fe-Mn-TiC composites are shown in figures 1 and 2. In the Fe-Mn-C molten alloy, pure titanium reacts with the available carbon and appears as in-situ TiC. Due to the reduced free energy and weak manganese carbide stability [2, 8], TiC stabilizes in the matrix of Fe-Mn-C. Titanium does not form double carbide (e.g., (Ti, Mn) C) with manganese but does form a very stable TiC at a temperature much higher than that at which manganese and cementite are formed [6].

During the solidification process, as the cooling rate varies TiC crystallize in the matrix of Fe-Mn [10]. The TiC nucleated at 1,600°C will be in regular shapes like circle, rectangle, square, and the TiC precipitate later will be in irregular with varying shapes in the matrix. At the reaction temperature, diffusion of carbon is reduced by TiC particles, and larger TiC will be appearing in the metal matrix. This may lead to lower super saturation of the molten liquid and results in a few nucleation's are, thus enhancing the TiC crystal size. This behavior of the TiC precipitation is clearly observed in Fe-Mn-TiC composites. Manganese increases the transformation of carbon into graphite in the steel and decreases the carbon content and leads to more ferrite [11-13]. High manganese steel gives more volume fraction of TiC with ferrite and pearlite along with varying sizes as well as shapes due to the lower super saturation. In Fe-Mn-TiC composite, varying manganese content decreases the dissolved carbon in the matrix and increases the grain size of the precipitated TiC particles. As the carbon content of the pearlite is reduced, ductility of the metal increases. Hardness is increased from composites A1 to A4 due to change in the volume fraction of TiC as well as change in matrix microstructure. The results of micro hardness reveals that the micro hardness increases with increase in TiC because the microstructure changes.

The in-situ TiC particles in specimens A1 to A4 contribute to improvement in wear resistance. TiC reinforced with larger volume fraction have good wear resistance than to TiC reinforced with fine particle. Jipeng Jiang et al. [14] produced Fe-TiC composites by In-situ method and studied on wear behavior of Fe-TiC composites. They reported that as the volume fraction of TiC and size increases the wear resistance increases. This is because increasing in TiC particles can be used for load-bearing elements in steel based composites thereby increasing their wear resistance.

Figure 3 and 4 shows that the variation of wear loss versus volume fraction of TiC for Fe-Mn-TiC composites investigated in the present work. It is evident from the results as the volume fraction of carbide increases the volume loss decreases in all composites. The curve shows the same general trend in all the cases. Figure 5 and 6 shows that the scanning electron micrographs of worn out surfaces of specimens A1 and A4 respectively. The worn surfaces of specimen A is relatively smooth with deep groves because of no TiC particles in the specimen. The specimen A4 surfaces have a smooth appearance owing to the resistance to scratching offered by the reinforcing TiC particles. In the present study, the specimens A3 and A4 are having more TiC particles, also excellent wear resistance and good interfacial compatibility of TiC particle there by promoting strong reinforcement-matrix bonding which enhances the hardness and wear resistance.

V. CONCLUSION

Fe-Mn-TiC composites containing TiC particles are produced by reacting Ti with carbon in Fe-Mn molten metal. Structure characterization and hardness measurement was performed on composites specimens and wear test are also conducted by varying applied load and sliding distance. Based on the result of this investigation the following conclusion can be drawn as follows.

1. Fe-Mn-TiC composites can be produced by varying TiC in molten Fe-Mn alloy by In-Situ method. .
2. Rockwell and micro hardness of the Fe-Mn-TiC composites increases with increasing in volume fraction of TiC.
3. Wear resistance of the composites increases with rise in volume fraction of TiC with respect to applied load and sliding distance.
4. Fractography clearly indicates non-uniform wear of Fe-Mn-TiC composites which is due to increase in wear resistance.

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