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Microstructure and Wear Behavior of (Ti,V)C Reinforced Ferrous Composite

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A (Ti,V)C/Fe composite was produced by a process which combines in situ synthesis with powder metallurgy technique using Ti, Fe, FeV and carbon powder. The microstructure of the Fe-(Ti,V)C composite was studied by scanning electron microscope and x-ray diffraction. The results show that the production of an iron matrix composite reinforced by (Ti,V)C particulates using the process is feasible. Fine (Ti,V)C particles are uniformly dispersed in the pearlite. The Fe-(Ti,V)C composite possesses excellent wear-resistance under the condition of dry sliding with heavy loads.

Keywords Fe-(Ti,V)C composite, in situ synthesis, microstructure, wear-resistance

1. Introduction

Composite materials with steel matrix and ceramic particle reinforcements provide scope for producing relatively inexpensive wear-resistant materials. Most of the work on iron-based composites has involved TiC reinforcement, which is introduced in the iron matrix through a powder metallurgy (P/M) route (Ref 1). The typical advantages of the route are raw material savings and low energy costs. In addition, P/M technique allows a higher content of alloying elements and the addition of the ceramic particles (Ref 2). However, the materials produced via this technique generally suffer from the problem of contaminated matrix-reinforcement interfaces. From this view point, the techniques involving the in situ generation of the reinforcing phase have emerged as a preferred synthesis route for these materials. In situ techniques involve a chemical reaction resulting in the formation of a very fine and thermodynamically stable ceramic phase within a metal matrix. As a result, the reinforcement surfaces are likely to be free from gas absorption, oxidation or other detrimental surface reaction contamination, and the interface between the matrix and the reinforcement bond tends to be stronger (Ref 3). Some of these technologies include exothermic dispersion (XD), liquid-solid or liquid-liquid reactions, and self-propagation high-temperature synthesis (SHS).

In addition, in situ formation of dual carbides (TiC and other carbides) in ferrous composites has been researched. For example, Dogan and Hawk (Ref 4) formed in situ TiC and $(Cr,Fe)_7C_3$ carbides in Fe-based composites; Farid et al. (Ref 5) in situ synthesized TiB_2 and TiC in stainless steel matrix composites; Jiang et al. (Ref 6) in situ produced (TiW)Cp/Fe composites. However, works concerning VC as an alternative addition to TiC/Fe matrix composites are scare.

The present work describes the fabrication, microstructure, and wear behavior of dense (Ti,V)C/Fe-matrix composites by an in situ method.

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2. Experimental Procedure

The starting powders were Ti, Fe, Ferrovandium (Fe-50wt.%V) and carbon black. The powders were mixed in a composition of 19.5 wt.% Ti, 17 wt.% FeV, 56.5 wt.% Fe, and 7 wt.% C. Powders mixing was done by planetary ball (QM-1SP, China) milling at 180 rev min^{-1} for 24 h. The jars for powders mixing were made of stainless steel. The balls for milling, which were made of stainless steel, were weighed to achieve a ball-to-powder ratio of 6:1. After mixing, the powder was characterized by x-ray diffraction (XRD) using Cu-Kα radiation. Samples of 16 mm diameter × 10 mm height were manufactured by uniaxial die pressing at 350 MPa. Sintering was performed in the 1350-1440 °C range in a vacuum furnace for 1 h followed by furnace cooling. The sintered density was determined by Archimedes' principle according to ASTM C373-72.

Microstructures were examined with a JSM-5900LV scanning electron microscope (SEM). Phase identification was carried out on a Philips x-ray diffractometer. Dry sliding wear test was carried out on a MM-200 wear-test machine. Wear rings, i.e. upper specimens, were made from hardened alloy-steel with a hardness of 55 HRC and lower specimens with a dimension of 10 × 10 × 17 mm were cut from the quenched medium-carbon steel and the samples with a Fe-(Ti,V)C composite. The loads were 196, 392, and 588 N, the rotative velocity was 400 rpm, and the wear stroke was 2000 m. The average width of the wear trail was measured with the help of a tool-microscope, and the wear volume was calculated with the following formula:

$$V = B\left\{r^2 \sin^{-1}(b/2r) - b/2\left(r^2 - b^2/4\right)^{1/2}\right\} = Bb^3/12r\,(\mathrm{mm}^3)$$

where B is the width of wear ring (mm), b the width of wear trail (mm), and r is the out radius of wear ring (mm).

3. Results and Discussion

3.1 The Formation of Double Carbide Solid Solution (Ti,V)C

The microstructure of the Fe-(Ti,V)C composite shown in Fig. 1 reveals many gray particles that are rich in Ti, V, and C. The TiC-VC system has complete solid solubility because the carbides share a cubic NaCl-type structure and the atomic radius of each metal is not very different, thus fulfilling the Hume-Rothery condition. The metals can be replaced or moved without jeopardizing the stability of the structure, so their distribution inside the solid solution will be random (Ref 7). The preceding discussion suggests that the gray particles in Fig. 1 are (Ti,V)C.

3.2 Densification

The densification behavior of the Fe-(Ti,V)C composite is shown in Fig. 2. Initially, the density increases as the sintering temperature is increased, reaches a maximum for the specimen sintered at 1400 °C, and decreases beyond this temperature. The reasons might be as follows: according to the pseudo-binary equilibrium phase diagram of Fe-TiC, the eutectic temperature is 1350 °C (Ref 8); therefore, a normal liquid phase sintering stage occurs when sintering temperature is 1350-1440 °C. With the increase of sintering temperature, the wettability between liquid phase and (Ti,V)C reinforcement is improved, which intensifies dissolution-precipitation of (Ti,V)C particles and increases the amount of liquid phase. As a result, densification increases. However, excess sintering temperature may cause severe volatilization of liquid phase (because of vacuum sintering), which results in the formation of voids in the sintered samples, thereby decreasing densification.

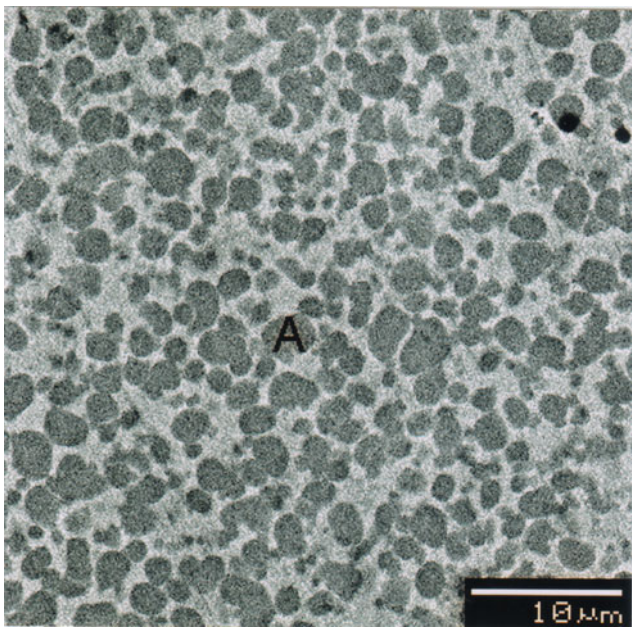

Fig. 1 Microstructure of Fe-(Ti,V)C composite sintered at 1400 °C. Composition of point A in Fig. 1: 54.21 wt.% Ti, 22.36 wt.% V, 18.23 wt.% C, and 5.2 wt.% Fe

3.3 Phase Identification of Fe-(Ti,V)C Composite

Figure 3 shows the characteristic XRD patterns of initial powder mixture from which the presence of α-Fe, α-Ti, FeV and graphite is detected.

The diffraction pattern for the Fe-(Ti,V)C composite sintered at 1400 °C is shown in Fig. 4. The bcc-Fe binder was unchanged with respect to the original powder, while the formation of (Ti,V)C solid solution is seen in the composite.

3.4 Microstructure of Fe-(Ti,V)C Composite

Figure 1 shows the scanning electron micrograph of Fe-(Ti,V)C composite. The gray areas are (Ti,V)C particles and the lighter region is Fe matrix. It can be seen that (Ti,V)C particles are uniformly dispersed in the matrix. Figure 5 shows the scanning electron micrograph of Fe-(Ti,V)C composite etched by 4% nitric acid and alcohol solution. It can be seen that the matrix microstructure of Fe-(Ti,V)C composite is pearlite.

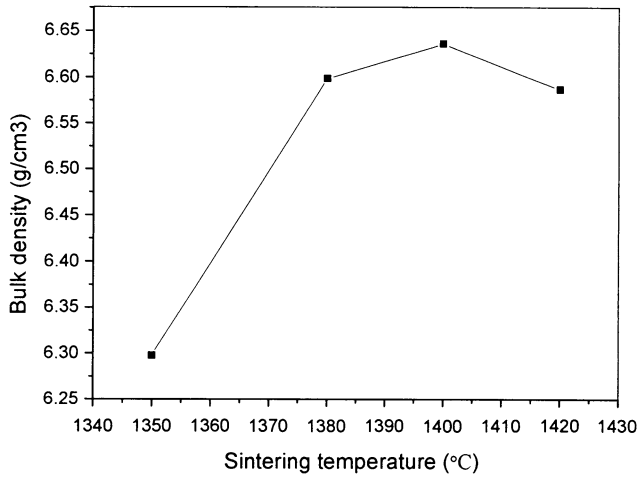

Fig. 2 Effect of sintering temperature on the apparent density of Fe-(Ti,V)C composite

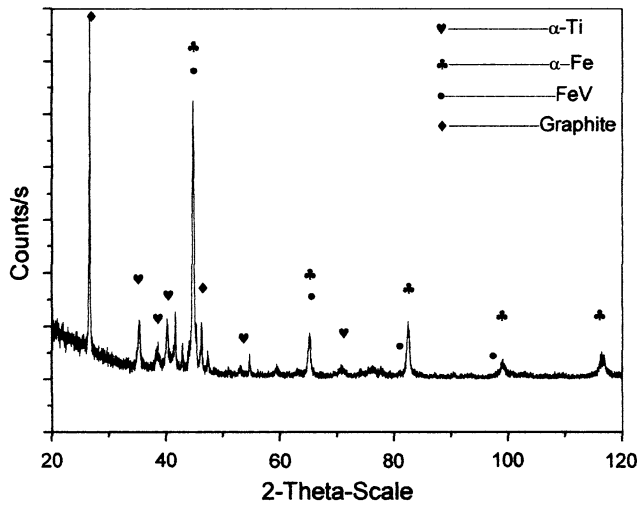

Fig. 3 X-ray diffraction pattern of initial powder mixture

3.5 Wear-Resistance of Fe-(Ti,V)C Composite

Under the condition of dry sliding wear with loads of 196, 392, and 588 N, the wear-volumes of the Fe-(Ti,V)C composite and the hardening medium-carbon steel are presented in Table 1. It can be found that the Fe-(Ti,V)C composite possesses great wear-resistance, being 6.3, 9.41, and 11.6 times that of the hardened medium-carbon steel under 196, 392, and 588 N load, respectively. Figure 6 shows the photomicrograph of the wear trail, the Fe-(Ti,V)C composite has a lower wear volume, while the serious adhesive wear is distinctly seen in the sample of the hardened medium carbon steel. The superior wear-resistance of Fe-(Ti,V)C composite is mainly attributed to the very hard (Ti,V)C particles that effectively reinforced the matrix and protected it from severe abrasion.

Table 1 Wear volume of Fe-(Ti,V)C composite and hardened medium-carbon steel

Materials	Wear volume, mm^3		
	Under 196 N	Under 392 N	Under 588 N
Hardened medium-carbon steel	9.71	32.38	121.43
Fe-(Ti,V)C composite	1.54	3.44	10.42

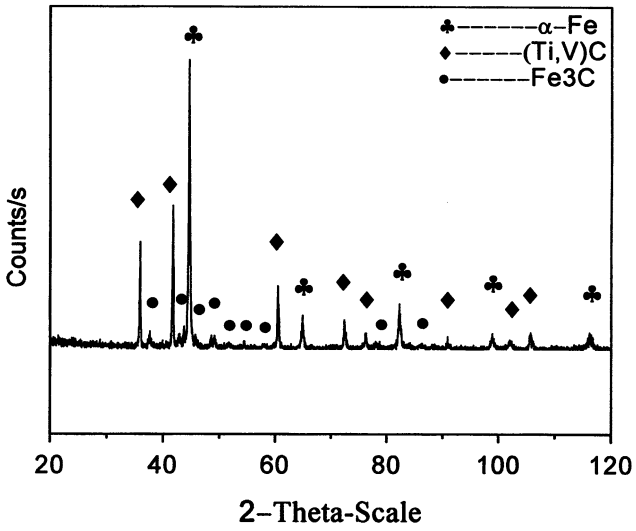

Fig. 4 X-ray diffraction patterns of Fe-(Ti,V)C composite sintered at 1400 °C

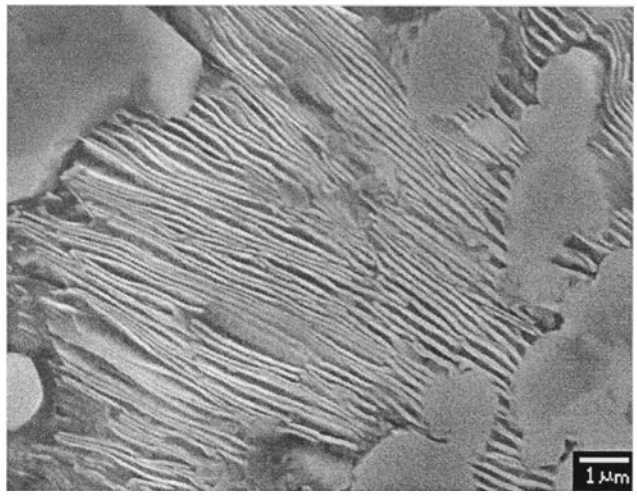

Fig. 5 SEM micrograph of Fe-(Ti,V)C composite etched by 4% nitric acid and alcohol solution

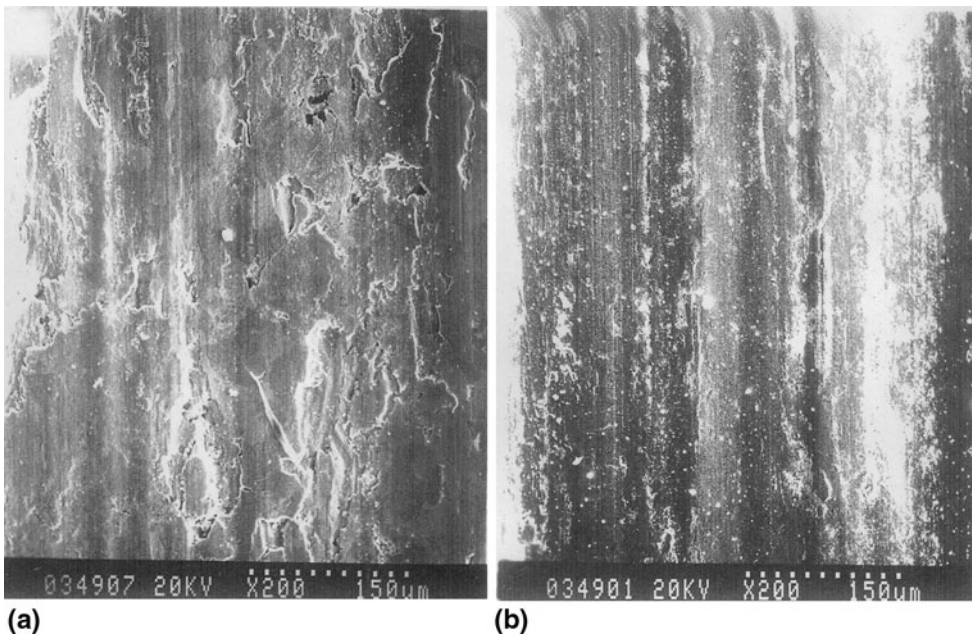

Fig. 6 SEM micrographs of wear trail of (a) hardened medium-carbon steel (588 N) and (b) Fe-(Ti,V)C composite (588 N)

4. Conclusions

Using a process that combines in situ reaction with powder metallurgy techniques, an iron base composite, reinforced by (Ti,V)C particles was produced. The (Ti,V)C particles generated in situ are uniformly dispersed in the matrix. Under the condition of dry sliding with heavy loads, the Fe-(Ti,V)C composite offers a high wear-resistance.

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