

Preparation and characterization of TiC particulate locally reinforced steel matrix composites from Cu–Ti–C system with various C particles



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ABSTRACT

The fabrication of steel-matrix composites locally reinforced with TiC particulates by the self-propagating high-temperature synthesis (SHS) reactions in the 20 wt.% Cu–Ti–C system with various C particle sizes during casting has been investigated, respectively. The composites synthesized with $\sim 1\ \mu\text{m}$ and $\sim 38\ \mu\text{m}$ C particles consist of TiC, Cu and γ -Fe phases, while the one synthesized with $\sim 150\ \mu\text{m}$ C particle mainly consists of TiC, Cu, γ -Fe and Fe_2Ti phases. With the increase in the C particle size, the interface bonding between the reinforced region and matrix becomes poor, as well as the number of pores and blowholes in the locally reinforced region increases. The hardness and wear resistance of the composites are significantly higher than those of the matrix. With the decrease of the size of C particle, the hardness and wear resistance of the composites increase.

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1. Introduction

It is well established that the steel matrix composites commonly have a good combination of hard ceramic (e.g. TiC, TiB_2 , WC and Al_2O_3) reinforcements and ductile metallic matrix, which make them become a promising candidate in wear resistance applications [1–4]. Generally, there are several methods for fabricating the particulate reinforced steel matrix composites, such as powder metallurgy [5], conventional melting and casting [6], reactive sintering [7,8], and self-propagating high-temperature synthesis (SHS) [9,10]. Among several fabrication techniques to synthesize in situ ceramic particulates locally reinforced steel matrix composites, SHS technology has attracted much attention because of its self-generation of energy required for the process, high-purity products as a result of the volatilization of some low boiling point impurities at elevated temperatures, high productivity and low energy consumption [11,12]. Therefore, the SHS and traditional casting routes provide an easy process to produce ceramic particulate locally reinforced steel matrix composites [13,14]. It combines

the advantages of the SHS reaction with the easiness and the casting process with high efficiency.

Among various ceramic particulates, TiC is a potential material because of its outstanding properties, such as high hardness, low density, high melting temperature, high modulus, good wear and corrosion resistance as well as good wettability and stability in the steel melt compared to other ceramics [15]. Therefore, the TiC is widely used as the reinforcement in steel matrix composites. Recently, TiC particulate locally reinforced steel matrix composites fabricated by SHS reaction from a Metal (Me)–Ti–C systems (Metal: Al, Cu, Ni, Fe and so on) have been the subject of intensive investigation [16–18]. Unfortunately, the very high reaction heat released during the formation of pure TiC could cause the appearance of large number of pores in the local reinforcing region. These pores can influence the wear resistance property of the steel matrix composites greatly. If the volume fraction of the TiC particulates in the local reinforcing region decreases, the porosity may decrease due to the decreasing combustion temperature in the SHS reaction. However, it may lower the wear resistance properties of the local reinforcing region.

Thus, in the present study, an attempt is carried out to decrease the porosity of the local reinforcing region and improve the resistance property by changing the sizes of C particle in the Cu–Ti–C system with no change of the volume fraction of the reinforcement in the local reinforcing region. The microstructures, porosity, hardness and wear resistance of the composites synthesized by using 20 wt.% Cu–Ti–C system with various sizes of C particle are investigated, respectively. It is expected that the preliminary results could be significant in promoting the development and practical application of the in situ particulate locally reinforced steel matrix composites.

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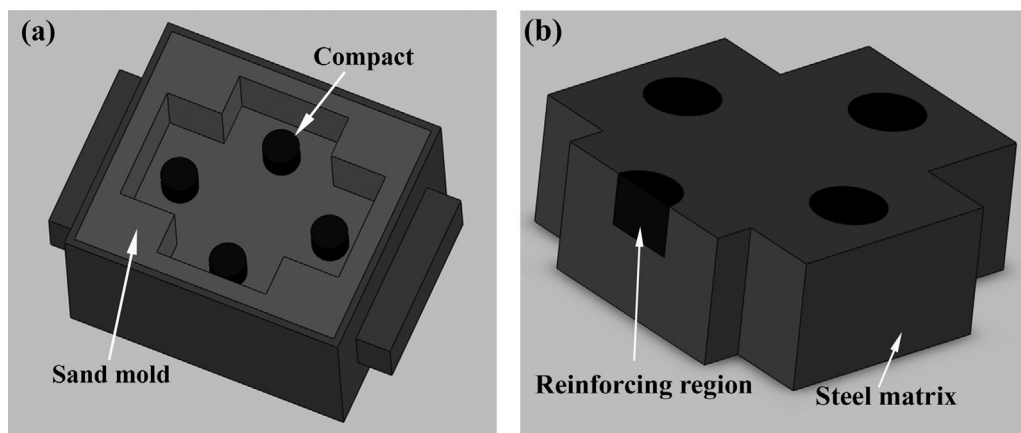


Fig. 1. Schematic diagram of the (a) compacts located in the sand mold and (b) composite material casting.

2. Experimental details

The starting materials were made from commercial powders of Cu (99.5% purity, average particle size of $\sim 6 \mu\text{m}$), Ti (99.5% purity, average particle size of $\sim 15 \mu\text{m}$) and C (99.9% purity, average particle size of $\sim 1 \mu\text{m}$, $\sim 38 \mu\text{m}$, $\sim 75 \mu\text{m}$ and $\sim 150 \mu\text{m}$, respectively). Ti and C powders with a ratio corresponding to that of the stoichiometric TiC mixed with 20 wt.% Cu content were used for the powder blends. After mixing for 6 h, the blends were uniaxially pressed into cylindrical compacts (about 22 mm in diameter and 14 ± 1 mm in length) to obtain green densities of $70 \pm 2\%$ theoretical density. After being dried in an oven at about 150°C for 3 h to remove any trace of moisture, the compacts with various C sizes were placed at the bottom of a special sand mold, as shown in Fig. 1a. In addition, the combustion characteristics for the reactions with various C sizes were also studied by the differential thermal analysis (DTA, Rigaku-8150, Japan) experiments, which were conducted in a flowing argon gas (flowing rate: 60 ml/min) using a heating rate of $40^\circ\text{C}/\text{min}$.

The medium manganese steel (0.72C–0.45Si–8.6Mn–Fe balance, all in wt.%) melt was prepared in a 5 kg medium-frequency induction furnace. Subsequently, the molten steel (about 1500°C) was poured into the sand mold to ignite the SHS reactions of these compacts. After solidification, composite castings were removed and sectioned in the side position, as shown in Fig. 1b.

Because it was difficult to achieve the kinetics of SHS reaction of the Cu–Ti–C system with various sizes of C particle in the liquid steel, the SHS experiments were conducted first in a self-made vacuum vessel in order to offer some guidance to the fabrication and investigation of the locally reinforced steel matrix composites. The SHS experiments were conducted in a self-made vacuum vessel filled with Ar at 1 atm. The compacts were ignited on the graphite flat which was placed at the top of tungsten electrode and heated by the heat of arc. A small hole (2 mm in diameter and 2 mm in depth) was drilled at the top of the compact, and a thermocouple pair of W/Re5-W/Re26 (0.5 mm in diameter) was inserted into the hole and linked up with a temperature acquisition recorder by means of which a temperature–time curve could be recorded. More details about the experimental apparatus and procedure for the SHS reaction were given in a previous article [19].

The wear tests were conducted under a load of 35 N using a pin-on-disk apparatus and the 600 mesh SiC abrasive papers were used as the counterface. The wear rate is defined as volume loss divided by sliding distance, and the volume loss is obtained from the ratio of weight loss to the density of the sample. The densities of the samples were measured by Archimedes' water-immersion method. Microstructures were examined using

scanning electron microscopy (SEM) (Model JSM-5310, Japan) together with energy-dispersive spectrometry (EDS) (Model Link-Isis, Britain). The phases were identified by X-ray diffraction (XRD) (Model D/Max 2500PC Rigaku, Japan).

3. Results and discussions

3.1. Effect of C particle size on the thermal analysis

In order to understand the ignition reaction of the 20 wt.% Cu–Ti–C system with $\sim 1 \mu\text{m}$, $\sim 38 \mu\text{m}$ and $\sim 150 \mu\text{m}$ C particles, DTA experiments were conducted. The DTA curves and XRD patterns of the DTA products are shown in Fig. 2a and b, respectively. It was observed during the experiments that three strong exothermic peaks with the maximum at about 887°C , 975°C and 1021°C as well as two endothermic peaks with the minimum at about 966°C and 1006°C appeared in the 20 wt.% Cu–Ti–C system with $\sim 38 \mu\text{m}$ C particle [20], respectively. For the reactants with $\sim 150 \mu\text{m}$ C particle, the temperatures of the three exothermic peaks and two endothermic peaks are very similar to those in the reactants with $\sim 38 \mu\text{m}$ C particle. DTA curves indicate that two exothermic peaks with the maximum at about 975°C and 1072°C appeared in the reactants with $\sim 1 \mu\text{m}$ C particle. It is different from the systems with $\sim 38 \mu\text{m}$ and $\sim 150 \mu\text{m}$ C particles.

According to the previous studies [20], when the 20 wt.% Cu–Ti–C system with $\sim 38 \mu\text{m}$ and $\sim 150 \mu\text{m}$ C particles was heated to 887°C , a large number of Ti_xCu_y compounds were formed initially via solid-state diffusion reactions between Cu and Ti particles. The melting points and eutectic points of the Ti_xCu_y compounds are much lower than those of Cu and Ti. Once the temperatures reached the melting points or eutectic points of the Ti_xCu_y compounds, the Cu–Ti liquid formed quickly. Therefore, the endothermic peak at 966°C corresponds to the formation of the Cu–Ti liquid phase. The formation of liquids and continuous heating significantly promote the diffusion of C and the formation of the Cu–Ti–C liquids; subsequently, TiC particulates were precipitated out of the liquids, which was an exothermic reaction, corresponding to the two exothermic peaks with the maximum at about 975°C and 1021°C in the DTA curves. According to these results, the ignition temperature of the SHS reaction could be prophesied at about 960°C in the reactants with $\sim 38 \mu\text{m}$ and $\sim 150 \mu\text{m}$ C particles. According to the XRD patterns of the DTA products with $\sim 38 \mu\text{m}$ and $\sim 150 \mu\text{m}$ C particles quenched from 1200°C , as shown in Fig. 2b, a large quantity of TiC are formed, and a small quantity of C and Ti_xCu_y compounds remain as well.

One question is how TiC is formed in the 20 wt.% Cu–Ti–C system with $\sim 1 \mu\text{m}$ C particle. It can be seen from Fig. 2a that the two

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