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Short Communication

Fabrication of in situ TiC locally reinforced manganese steel matrix composite via combustion synthesis during casting

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ABSTRACT

In situ TiC particulates locally reinforced manganese (Mn) steel matrix composite was successfully fabricated via combustion synthesis of (Fe,Ti)–C system during casting. XRD results reveal that the phases of the composites consist of TiC, α-Fe and austenite. Microstructure of the locally reinforced manganese (Mn) steel matrix composite consists of three separate regions, i.e. a TiC particulate-reinforced region, a transition region, a steel matrix region. TiC particles in the reinforced region, having fine size of 2 μm, are distributed uniformly. The hardness and wear resistance of the TiC particulates locally reinforced composites are much higher than those of quenched Mn13 steel. Furthermore, the microstructure formation mechanism of the composite was discussed.

1. Introduction

High manganese austenite steels, as traditional wear-resistance alloys, possess high toughness and excellent wear resistance under high impact energy work conditions because of the high work-hardening capacity [1–4]. Metastable austenite manganese steels, in comparison with high manganese austenite steels, perform better wear resistance under low stress abrasive wear condition [5]. However, the wear resistance of medium austenite manganese steel under high stress abrasive conditions needs to be improved.

In order to improve the wear resistance of metal materials, the incorporation of ceramic particulate reinforcements into steel or iron matrix to produce composites with excellent wear resistance has been extensively researched. Although most of work on MMC is centered on monolithic reinforced steel MMCs, there is also considerable interest in developing locally (including surface) reinforced steel MMCs [6,7]. Compared to monolithic reinforced steel MMCs, locally reinforced steel MMCs exhibit the following advantages, i.e. more practicality, lower production cost and well castability [6,8,9]. Combustion synthesis is an effective process to produce metal matrix composites containing high volume fraction of reinforcements. However, its inherent drawback is that the presence of porosity in the products is inevitable [10]. While full density products can be fabricated via traditional casting process.

Titanium carbide is considered as a promising reinforcement of steel MMCs because of its high hardness (3000–3200 HV) [11], high melting point (3067 °C), high chemical and thermal stability, good wettability and relative thermal stability with steel [12]. In present work, ferrotitanium alloy and graphite powder blends were used as reactant to form TiC particles instead of titanium, iron and graphite powder blends, not only because ferrotitanium could offer titanium element reacting with graphite and iron element served as a diluent during combustion reaction, but also because it is cheaper than titanium and iron.

In this study, locally reinforced medium austenite manganese steel matrix composite was fabricated via combustion synthesis of (Fe,Ti)–C system during casting based on the following consideration: firstly, the combustion reaction of the reactant performs is expected to be ignited by the high temperature steel melt during casting; secondly, after the combustion reaction is completed, the porosity of the product would be filled with liquid steel owing to capillary spreading, resulting in near full density composite; and finally, the local incorporation of TiC particles into medium austenite manganese steel is expected to provide better wear resistance under high stress abrasive wear condition.

2. Experimental procedure

The starting materials in present work were made from high ferrotitanium (size 25–53 μm), low ferrotitanium (size 25–53 μm) and graphite powders (size ⩽53 μm, purity 99.9 wt.%). The composition of ferrotitanium is listed in Table 1.

For preparing performs, powder blends were used in Ti/C atomic ratio of 1:1 and with 60 wt.% Fe. Powder blends were dry–mixed for 24 h in a cylindrical stainless steel jar at mechanical rotation of

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Table 1
The composition (wt.%) of the (Ti,Fe) powders.

Materials	Ti	Al	Si	C	P	S	B	V	Sn	Fe
High ferrotitanium	65.05	4.5	1.5	0.15	2.0	0.03	0.03	2.5	1.5	Bal.
Low ferrotitanium	28.13	-	2.5	0.1	0.05	0.03	–	1.0	–	Bal.

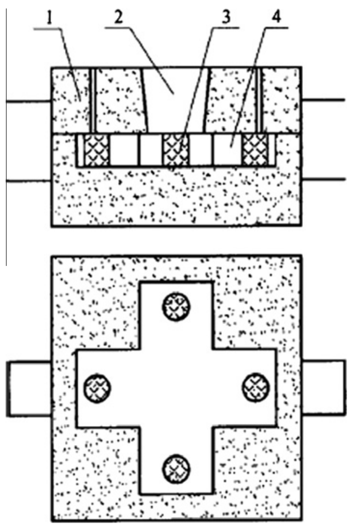

Fig. 1. Schematic diagram of sand mould.

Table 2
The chemical composition (wt.%) of the medium manganese steel matrix.

Matrix material	Composition				
Medium manganese steel	Mn	C	Si	S	P
	7.74578	0.82090	1.06130	0.00948	0.05503

50 rpm, and then were uniaxially pressed into cylindrical compacts with sizes of 22 mm diameter and 5 mm height under pressure of approximately 80 MPa. After being dried in an oven at about 120 °C for 5 h to remove any trace of moisture, the performs were placed at the bottom of a special sand mold, as shown in Fig. 1 [9]. During the compacting and drying process, the powders were wrapped by aluminum foil, preventing contact of oxygen in air.

A kind of medium manganese steel was selected as the matrix materials, of which the composition was listed in Table 2. The molten steel, prepared in a 5 kg medium-frequency induction furnace, was poured into the sand mould to ignite the combustion reaction. After solidification, the locally reinforced Mn steel MMCs were formed.

Metallographic specimens were polished through standard procedure and examined using optical microscopy to observe the microstructure features of the composites. A 4% nital solution (ethanol + 4 vol.% nitric acid) was used as the etchant of polishing samples. The microstructure of the etched specimens was examined with scanning electron microscopy (SEM) (JSM-5310, Japan) equipped with energy-dispersive spectroscopy (EDS) (Link-Isis, Britain) and X-ray diffraction (XRD) (D/Max 2500PC Rigaku, Japan).

The abrasive wear were tested under a load of 38 N using a ML-100 pin-on-disc apparatus. Both the quenched Mn13 steel and the reinforced composites, cut into rectangular bulk specimens with the sizes of 10 × 8 × 8 mm (pin), were loaded against a disc having contact area of 64 mm^2 and used as pin materials, while 360-mesh SiC abrasive paper was used as the counterface.

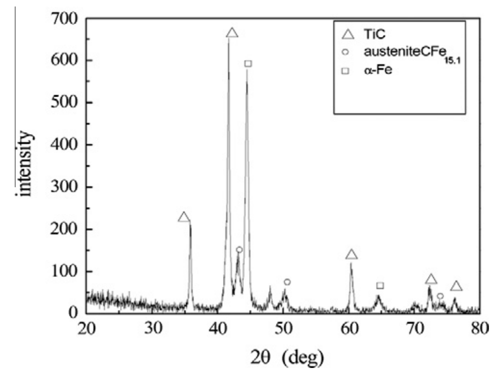

Fig. 2. XRD analysis of the composite.

3. Results

3.1. Microstructure of the locally reinforced Mn steel MMCs

XRD patterns of the composites are shown in Fig. 2, indicating that the phases of the composites consist of TiC, α-Fe and austenite. SEM of the composite shows that the microstructure of the composites could be divided into three different regions, i.e. a particulate-reinforced region, a transition region, a steel matrix region, as shown in Fig. 3a.

The reinforced region of the composites is dispersed uniformly with a great amount of fine reinforcement particles with the size of ~2 μm, as shown in Fig. 3e. The fine particles are characterized by the line scan of EDS. The result indicates that the fine particles are titanium carbides, as shown in Fig. 7.

In the transition region, it can be seen from Fig. 3a and b that the interface is clean. There are some particles diffusing into the matrix region, and cracks and pores are hardly found in this region. Thus the interface between the matrix and the reinforced region has a good and tight bonding. EDS line scans of the particles with the size of ~20 μm are shown in Fig. 4a, indicating that the composition of the particles mainly contains a considerable amount of manganese and iron elements. To further determine the composition of the particle, fixed-point analysis was also used, and the results are shown in Fig. 4b. It is worth mentioning that carbon element in the particles cannot be accurately determined due to the energy dispersive detector element limitation. Therefore, according to the morphology and EDS results, they are Fe–Ti–Mn–C particles. It is interesting that particles in this region are bigger than that in the reinforced region, as shown in Fig. 3c. In addition, the volume fraction of coarse particles increases with the distance near form the matrix region. The EDS line scan (Fig. 4c) indicates that the smaller particles also mainly contain manganese and iron elements. The content of carbon and titanium elements is much higher, and therefore, it is more likely to form TiC in comparison with the bigger particles. It is worth mentioning that a kind of sea-anemone-like phase was found in this region, as shown in Fig. 5a and b. They are surrounded by many titanium carbide particles with the size of ~1 μm. Furthermore, there is a long and narrow pore existing between this phase and the matrix in the reinforced region. The smaller particles are rectangular parallelepiped or some irregular polygon. The results