In Situ Production of Fe–TiC Composites by Self-propagative High-temperature Synthesis Reaction in Liquid Iron Alloy

Q. F. GUAN, Q. C. JIANG, Y. Q. ZHAO and C. H. LIU

Department of Materials Science and Engineering, Jilin University, Changchun 130025, China.

(Received on January 7, 2002; accepted in final form on March 4, 2002)

1. Introduction

Particulate TiC-reinforced steel matrix composite was fabricated by using Ti–C–Al system self-propagative high-temperature synthesis (SHS) reaction in the liquid steel alloy. It is found that high volume fractions and good dispersion of well-rounded and fine size TiC reinforcement particles can be produced in the steel, which exhibit higher hardness and abrasive wear resistance than matrix materials.

Iron-base TiC metal–matrix composites are currently available and produced by powder metallurgy routes involving the addition of TiC powders to iron alloy powders. Primary applications for these materials are for cutting, machining and wear resistance. There are several potential advantages in terms of production costs and efficiency if such composites can be produced by liquid-based routes involving the in-situ formation of the filler phase. These advantages include the reduction in the number of process steps involved in the composite production as a result of the removal of the need for intermediate formation of the TiC filler material. A further advantage of an in-situ route is that the surface of reinforcements generated in-situ tend to remain clean, and the matrix-filler interface bond therefore tends to be stronger. The use of a liquid-based route provides the opportunity of producing near-net-shape final components directly by casting. The identification of conditions whereby good dispersions of the filler in the liquid metal can be maintained, and porosity and detrimental matrix-filler reactions can be minimized, is essential to the development of production routes based on this approach.

Self-propagating high-temperature synthesis (SHS), also known as combustion synthesis, is gaining attention as a technique for synthesis of refractory materials. In this technique, a reactant compact is ignited at one end by a high energy input, and, subsequently, a layerwise combustion wave propagates throughout the reactant compact, converting it to product. It has many attractive advantage, such as high purity of products, low processing cost, and energy and time efficiency. A wide variety of materials have been produced by this method. Recently SHS reaction in the Ti–C–Al system has been widely investigated because of its lower ignited temperature, about 873–1023 K, which is much lower than the temperature of liquid steel alloy. Then as-cast iron-base TiC metal–matrix composites can be fabricated.

A previous work has examined the feasibility of producing Mg–TiC composites directly by SHS reaction of Ti–C–Al powder mixtures in liquid magnesium alloy with temperature 1073–1123 K. Chambers et al. have conducted a fundamental study of the effect of cooling rates on the solidification behavior of liquid Fe–Ti–C melts with the aim of developing a casting route for Fe–TiC composites production. In-situ generation of dispersions of niobium and vanadium carbides in liquid steel alloys has previously been achieved by Beeley and co-workers by the addition, either sequential or simultaneous, of niobium or vanadium and graphite to liquid steels before casting.

The aim of the work reported here was to provide an initial assessment of the feasibility of obtaining good dispersions of TiC in iron matrices by direct SHS reaction in liquid iron alloys. These initial experiments were performed on a small laboratory scale.

2. Experiment

The characteristics of the powders used in the present study are listed in Table 1. Titanium and carbon black powders with an atomic ratio of 1:1 were mixed with various amounts of aluminum powder (10–40 wt% of Ti+C+Al) as the starting powders. The reactants were mechanically blended by a ball mill. Then the resulting mixture was pressed into cylindrical compacts, 30 mm in diameter and 40 mm in length, by using a stainless-steel die with two plungers. The compacts were pressed at pressures of about 70 MPa to give densities of about 65% of the theoretical density. The resulting compact was placed in the reactor, argon glove box, which was filled with argon gas at 0.1 MPa. The combustion reaction was ignited by heating the bottom surface of the compact for several minutes through the tungsten filament. The temperature at which ignition occurs was measured by thermocouples.

A commercial manganese steel, which consisted of C-0.76 wt% and Mn-9.6 wt%, was selected as the matrices for the composites. Four compacts with various amounts of aluminum power (10, 20, 30, and 40 wt%) were placed on the every side of the sand mold with a cross shape, respectively. As shown in Fig. 1, the steel was melt in a 5 kg medium-frequency induction furnace. The melt steel was then poured into the sand mold to produce an ingot. The side regions of the as-cast ingot were sectioned, polished, and examined under a scanning electron microscopy (SEM).

Table 1. Characteristics of Al, C and Ti powders.

| Reagent   | Particle size (μm) | Purity (%) | Source                     |
|-----------|-------------------|------------|----------------------------|
| Aluminum  | <29               | 99.80      | Northeast Light Alloy Co., Ltd., China |
| Graphite  | <38               | 99.99      | Jilin Graphite materials Co., Ltd., China |
| Titanium  | <25               | 99.50      | General Research Institute for Nonferrous Metals, Beijing, China |

© 2002 ISIJ
with energy dispersive spectroscopy (EDS). The hardness and wear resistance properties of these samples were tested. The microhardness was measured at an applied load of 100g. A pin-on-disk apparatus was used for evaluating the abrasive wear resistance. The disk was covered with commercial silicon carbide abrasive paper (grit grade 600 of about 12.4 μm average particle size). The conditions of this experiment were as follows: dry friction, 15N load and no lubricant.

3. Results

Typical temperature–time histories during heating and ignition for reactant compacts containing various amounts of aluminum are shown in Fig. 2. The temperature rise before the abrupt increase is caused by heat supplied by the heating coil, whereas the abrupt increase is caused by the combustion reaction between titanium and carbon. Thus, the temperature at the point of the abrupt increase is defined as the ignition temperature. Figure 2 shows that the ignition temperatures of Ti–C–Al compacts of various amounts of aluminum are approximately between 840–920 K. XRD pattern (Fig. 3) reveals that there are only two phases, i.e. TiC and Al in the composites. The SEM micrographs of the surface of the product shown in Fig. 4 reveal good dispersions of well-rounded TiC particles of approximately 2 μm size. The above results suggest the possibility that the combustion reaction can be ignited as the compacts are placed in the liquid steel with much higher temperature than the ignition temperatures of Ti–C–Al compacts, and in-situ TiC particles are produced in the liquid steel, as a result in-situ Fe–TiC composites are fabricated.

The as-cast microstructure of the composite obtained from the compact with 20 wt% amount of aluminum power is shown in Fig. 5(a). The successful combustion reactions were produced in the liquid steel in all the preceding experiment conditions. Other compacts with various content of aluminum yield equally uniform microstructures in the composites. The X-ray dot map for elemental titanium is also shown in Fig. 5(b). They show good dispersion of TiC particles in the composites. It can be seen that the resultant microstructure consisted of a good dispersion of well-rounded reinforcement particles, approximately 2 μm size, in the steel. Figure 5(c) is a magnified SEM micrograph of Fig. 5(a). The EDS result illustrated in Fig. 5(d) reveals that the component of the reinforcement particles mainly consists of the elements of Ti and C. The other peaks, such as Fe and Mn peaks, were induced by matrix. It suggests that the reinforcement particles must be TiC particles. The fact was confirmed by the X-ray diffraction. The fairly good dispersion of the TiC particles in the steel matrix also suggests a good wetting between TiC particles and iron. The TiC
particles produced are of a rounded form, which is likely to be favorable of impact and wear resistance properties.

The properties of microhardness and wear loss of the composites are shown in Table 2. To evaluate the reinforced effect of TiC particles, the properties of matrix were also tested to compare with the composites. It can be seen that Fe–TiC in-situ composites fabricated exhibited much higher hardness and wear resistance than unreinforced manganese steel. This may be attributed to the presence of uniformly dispersed, well-rounded and fine size TiC particles in the matrix along with the clean interface between TiC and Fe.

### Table 2. Mechanical properties of manganese steel and composite.

| Specimen       | Composite | Matrix |
|----------------|-----------|--------|
| HV             | 654       | 322    |
| Weight loss (mg/m) | 4.70     | 6.52   |

4. Conclusions

The preliminary results reported show great promise. High volume fractions and good dispersions of TiC can be produced by SHS reaction in local regions of the workpiece or tool, which are particular needed higher hardness and abrasive wear resistance, by use of relatively cheap reagents and simple process.

Acknowledgement

This work was supported by the National Natural Science Foundation of China [50171029], to whom we are very grateful.

REFERENCES

1) Q. C. Jiang, H. Y. Wang and Q. F. Guan: Trans. Mater. Heat Treat. (China), 22 (2001), 38.
2) B. V. Chamber, T. Z. Kattanis, J. A. Cornie and M. C. Fleming: Solidification Processing, The Institute of Metals, London, (1987), 453.
3) P. A. Blackmore, A. J. Baker and P. R. Beeley: Solidification and Casting of Metals, The Metals Society, London, (1977), 533.
4) S. R. Tittagala, P. R. Beeley and A. N. Branley: Met. Technol., 10 (1983), 257.
5) P. R. Beeley, A. J. Baker and P. A. Blackmore: Solidification Technology in the Foundry and Casthouse, The Metals Society, London, (1983), 533.