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In situ fabrication of TiC particulates locally reinforced aluminum matrix composites by self-propagating reaction during casting

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Abstract

TiC ceramic particulates locally reinforced aluminum matrix composites were successfully fabricated via self-propagating high-temperature synthesis (SHS) reaction of Al–Ti–C system during aluminum melt casting. The SHS reaction could be initiated when Al contents in the green compacts ranged from 20 wt.% to 40 wt.%. With increasing Al contents, the ignition delay time was prolonged and the adiabatic combustion temperature was lowered. Using XRD and DSC analysis, the SHS reaction characteristic was discussed. The result showed that Al serves not only as a diluent but also as an intermediate reactant participating in the SHS reaction, determining the reaction process and its final producsts. The SEM images revealed a relatively uniform distribution and nearly spherical morphology of TiC particulates in the locally reinforced region, and excellent adhesion and gradient distribution between the TiC particulates reinforced region and Al-matrix. The size of the TiC particulates decreased obviously with increasing Al contents in the blends.

Keywords: Al-matrix composites; SHS; TiC particulates; Locally reinforced; Al contents

1. Introduction

The ceramic particulate-reinforced metal-matrix composites (MMCs) have attracted increasing interest in the automobile and aerospace industries as potential advanced engineering structural materials by virtue of high specific strength, stiffness and modulus, as well as high wear resistance, excellent elevated temperature resistance, low fabrication costs and good isotropic properties [1–6]. As a good reinforcement candidate in aluminum matrix composites, TiC ceramic exhibits many desirable features, such as high hardness, high melting point, high elastic modulus and low heat-conductivity coefficient, especially its good wettability and thermodynamic stability with molten aluminum [7–8]. There have been many reports about TiC particulates monolithically reinforced Al-matrix composites [9–12]. However, in light of materials practical service status, the local region properties of the materials (e.g., hardness, strength and wear resistance) usually plays an crucial role in deciding the service life of the components. Therefore, in many cases, what we really need is to improve the properties of only the local region of the work piece rather than to obtain a whole reinforced MMC [13]. If so, it will undoubtedly lessen the processing costs of the MMCs products due to saving precious reinforcements and will achieve optimal properties combination without losing much of the matrix property. Jiang et al. have fabricated some TiC/TiB_2 ceramic particulates locally reinforced Fe- and Mg-based MMCs by using self-propagating high-temperature synthesis (SHS) route [14,15]. Self-propagating high-temperature synthesis, also known as combustion synthesis (CS), is a kind of self-sustaining synthesis by heat release of starting powder from chemical exothermic reaction between elements or between elements and compounds. Ceramic particulate locally reinforced MMCs can be in situ synthesized in metallic melt by utilizing SHS reaction during the composite fabrication. But the “inert” matrix, which acts as a diluent, likely leads to the propagation of the combustion wave unstable or even extinguished. At present, few works or reports have been focused on the TiC particles locally reinforced Al-matrix composites, and the relevant information still remains limited.

In this study, the TiC particulates in situ locally reinforced Al-matrix composites using SHS reaction of Al–Ti–C system during casting were fabricated and its reaction behavior was investigated. The effect of aluminum contents in the preforms on the reaction behavior between Ti and C to form TiC particulates

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Table 1
Composition of designed preforms and starting materials (wt.%)

Performs no.	Al	Ti	C
1	10	72	18
2	20	64	16
3	30	56	14
4	40	48	12
5	50	40	10

reinforcements during casting and the as-cast microstructures of the composites were discussed in detail.

2. Experimental procedures

The starting materials were commercial powders of aluminum (99% purity, ∼40 μm in size), titanium (99% purity, ∼40 μm in size) and graphite (99.9% purity, ≤30 μm in size). The samples were prepared with titanium and graphite powders at a ratio corresponding to that of stoichiometric TiC and 10, 20, 30, 40 and 50 wt.% Al contents, respectively (as listed in Table 1). The powders were sufficiently mixed by ball milling for 5 h under the inert atmosphere, and then were pressed into cylindrical preforms (20 mm in diameter and 16 mm in height) by using a stainless steel die with pressure about 50 MPa to obtain 70 ± 5% relative density. Then the preforms were dried in a vacuum oven at 200 °C for 2 h.

A pure aluminum ingot of about 500 g in weight used as the matrix and ignitor was melted in a graphite crucible in an electric resistance furnace and heated up to 900 °C. The schematic diagram of the graphite mould acted as locally reinforced equipment is shown in Fig. 1. Considering the quick heat loss of the molten aluminum during casting, the mould was preheated to 500 °C to allow the in situ reaction of Ti and C taking place before solidification. The green preform was placed into the bottom of the preheated mould, and then the molten aluminum with 900 °C was poured into the mould in air immediately. The time interval from the pouring of the molten aluminum to the beginning of the SHS reaction, termed as the reaction delay time, was measured.

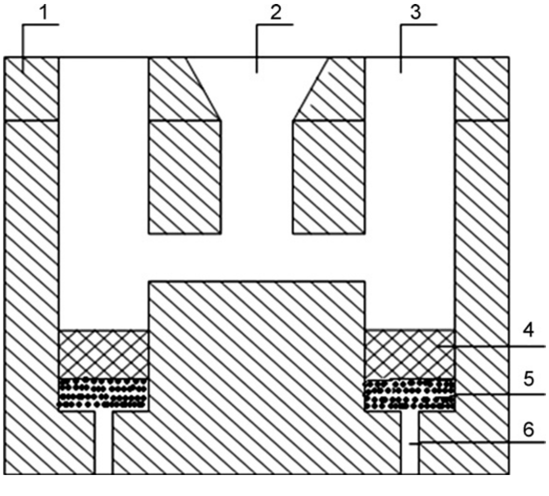

Fig. 1. Schematic diagram of locally reinforced experimental equipment: (1) graphite-mould; (2) sprue; (3) moulding chamber; (4) perform; (5) SiO_2 sands; (6) mould venting.

After the SHS reactions were completed and the samples were cooled down to room temperature, the as-cast specimens were sectioned, polished and etched for examination. The as-cast products were identified by X-ray diffraction (XRD) (Model D/Max 2500PC Rigaku) using Cu Kα radiation source with 40 kV voltage and 100 mA current. The microstructures of the locally reinforced composites were observed by field emission scanning electron microscopy (FE-SEM) (Model Sirion 200). The reaction features were analyzed using differential scanning calorimetry (DSC) (Model DSC-404).

3. Results and discussion

When the molten aluminum about 900 °C was poured into the graphite mould, after a few seconds of delay time, the flashes and sparks were dazzlingly observed indicating the SHS reaction occurs during casting. However, in our experiments, no SHS reaction took place for containing either 10 or 50 wt.% Al in the reactant mixture. The variation of the delay time with various Al contents (from 20 to 40 wt.%) in the reactant compacts are shown in Fig. 2. It is interesting noticed that the delay time is rather sensitive to the Al contents in the green preforms. With increasing Al contents, more Al powders in the compact will consume more heat to be melted, which undoubtedly prolong the SHS reaction delay time.

In the SHS reaction of $Ti_{(s)} + C_{(s)} + xAl_{(l)} \rightarrow TiC_{(s)} + xAl_{(l)}$, where the subscripts s, l and x denote the solid, liquid phase and Al content (wt.%), respectively, the amount of Al used as diluent is one of key factors to control the adiabatic combustion temperature T_{ad}. If it is assumed that the heat loss is negligible during the reaction, the standard state enthalpy balance equation is as following:

$$\sum n_i \Delta(H^{\theta}_{m,T_{ad}} - H^{\theta}_{m,298}) = -\Delta H^{\theta}_{298} \quad (1)$$

where $-H^{\theta}_{298}$, $\Delta(H^{\theta}_{m,T_{ad}} - H^{\theta}_{m,298})_i$ and n_i are the standard state enthalpy at room temperature, the molar enthalpy of formation and the molar number of its components, respectively. Referring

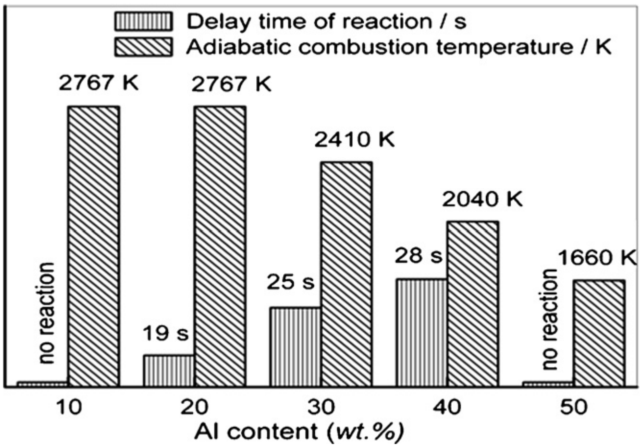

Fig. 2. The delay time (s) and adiabatic combustion temperature (K) vs. aluminum contents (wt.%) for SHS reaction.