Materials Research Bulletin 68 (2015) 283–288

Contents lists available at ScienceDirect

Materials Research Bulletin

journal homepage: www.elsevier.com/locate/matresbu

# Microwave combustion synthesis of *in situ* $Al_2O_3$ and $Al_3Zr$ reinforced aluminum matrix composites

Heguo Zhu [a,b,c,*], Bo Hua [a], Tao Cui [a], Jiewen Huang [a], Jianliang Li [a], Zonghan Xie [d,e,**]

[a] College of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, PR China
[b] Key Laboratory of Advanced Micro-Nano Materials and Technology, Jiangsu Province Higher Education Institutions, 210094, PR China
[c] Synergetic Center for Advanced Materials Research, Jiangsu Province Higher Education Institutions, 210094, PR China
[d] School of Mechanical & Electrical Engineering, Wuhan Institute of Technology, Wuhan 430073, PR China
[e] School of Mechanical Engineering, University of Adelaide, SA 5005, Australia

ARTICLE INFO

*Article history:*
Received 27 October 2014
Received in revised form 26 February 2015
Accepted 31 March 2015
Available online 2 April 2015

*Keywords:*
Aluminum matrix composites
Microwave combustion synthesis
Differential scanning calorimetry (DSC)
X-ray diffraction
Transmission electron microscopy (TEM)

ABSTRACT

$Al_2O_3$ and $Al_3Zr$ reinforced aluminum matrix composites were fabricated from Al and $ZrO_2$ powders by SiC assisted microwave combustion synthesis. The microstructure and reaction pathways were analyzed by using differential scanning calorimetry (DSC), X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and energy dispersive spectroscopy (EDS). The results showed that the heating rate during microwave synthesis was very high and the entire process took several minutes and that the ignition temperature of the reaction was much lower than that of conventional methods. In addition, the resulting microstructure was found to be finer than that prepared by the conventional methods and no cracks can be seen in the $Al_3Zr$ reinforcements. As such, the newly developed composites have potential for safety-critical applications where catastrophic failure is not tolerated.



## 1. Introduction

*In situ* metal matrix composites (MMCs) have shown considerable promise in structural applications due to their many attractive properties, including good thermal and electrical conductivities, high strength and fracture toughness, and excellent wear resistance [1–3]. When the reinforcements are formed by chemical reactions within the matrix, clean reinforcement/matrix interface, high thermal stability and good isotropic properties can result with low fabrication costs [4,5]. For the fabrication of *in situ* MMCs, the conventional method commonly employs one of three heating modes; namely: conduction, convection and radiation, which typically requires long fabrication time that increases process cost and adds heavy burden on environment [6]. Recently, microwave sintering has emerged as a quicker, cheaper and cleaner manufacturing technique and attracted much interest [7–10]. For example, microwave sintering not only considerably reduced the sintering temperature of $ZrB_2/B_4C$ ceramic, but also enhanced its density up to 97% [11]. Breval et al. [12] fabricated the WC/Co composites using the same method. They found that the fine WC particles can form uniformly in the matrix that yielded better mechanical properties than those obtained by conventional sintering. Microwave technique can also be used to sinter complex ceramic and intermetallic materials *in situ* from reaction systems such as Al–$TiO_2$–C and Al–$TiO_2$–$H_3B_2O_3$ [13,14] that exhibited clear advantages compared to conventional heating reactions [15–18]. Generally speaking, microwave heating can lower the synthesis temperature by about 200 °C measured by the DTA–TG analyses [19].

If the microwave heating method is used to synthesize *in situ* aluminum matrix composites (AMCs), what results can be produced? To date, no reports are available to answer this question. It is known that when the metal powder compact is heated by microwave, the temperature in the compact will increase due to the contact resistance between the powders. However, when the temperature increases up to the melting point of the metal powders, the contact resistance will decrease and even disappear. As a result, the microwave shield may form, and the temperature in the compact would drop. According to this analysis, if the reaction can take place before the melting of the

* Corresponding author at: College of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, PR China. Tel.: +86 25 84307689.
** Corresponding author at: School of Mechanical Engineering, University of Adelaide, SA 5005, Australia. Tel.: +61 8 8313 3980.
*E-mail addresses:* zhg1200@sina.com (H. Zhu), zonghan.xie@adelaide.edu.au (Z. Xie).

http://dx.doi.org/10.1016/j.materresbull.2015.03.074
0025-5408/

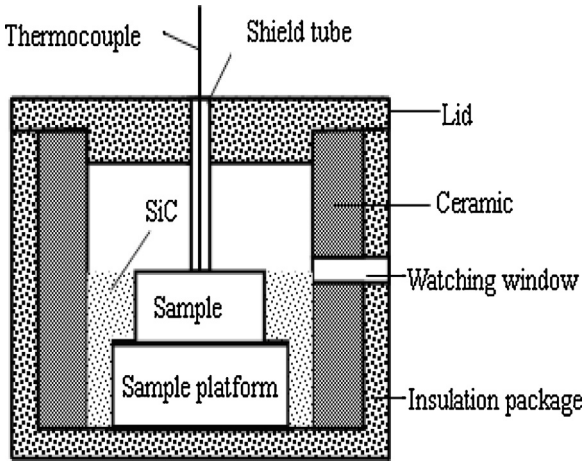


**Fig. 1.** Diagrammatic sketch of reaction chamber with assisted SiC powders used in the present study.

metal powders, the exothermic reaction heat can be used to drive the reaction to completion. However, if the reaction does not occur before the formation of the microwave shield, additional heat resources must be supplied, for instance, the addition of SiC powders that can absorb heat that propels the reaction to take place. In this paper, *in situ* aluminum matrix composites – ($Al_2O_3 + Al_3Zr$)/Al – were fabricated by SiC assisted microwave combustion synthesis. The microstructure and reaction process were examined and clarified by using differential scanning calorimetry (DSC), X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and energy dispersive spectroscopy (EDS).

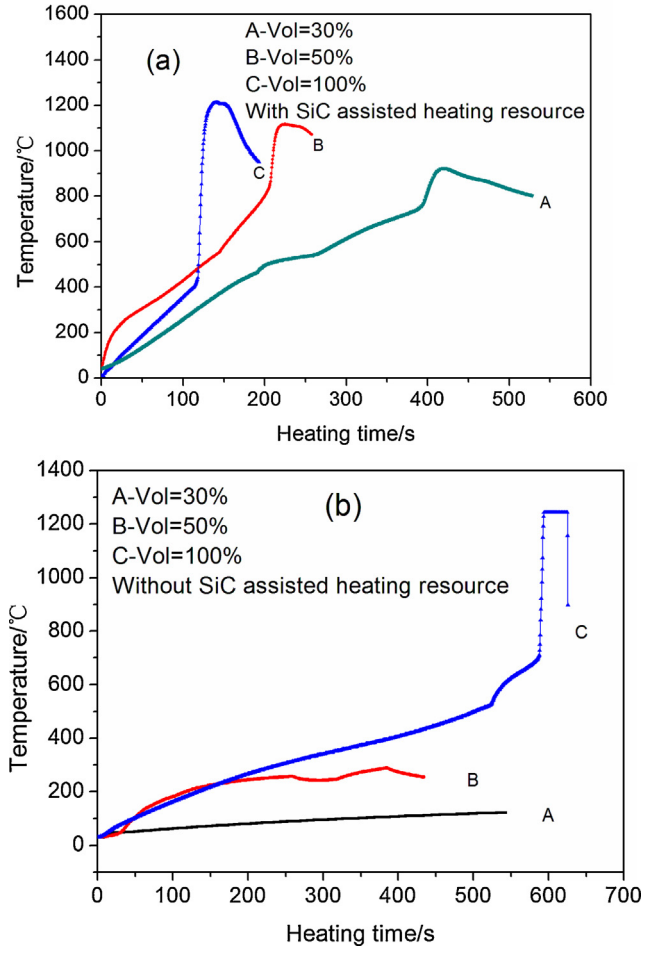


**Fig. 2.** Plots of temperature as a function of microwave heating time with SiC assisted heating resource (a) and without SiC assisted heating resource (b).

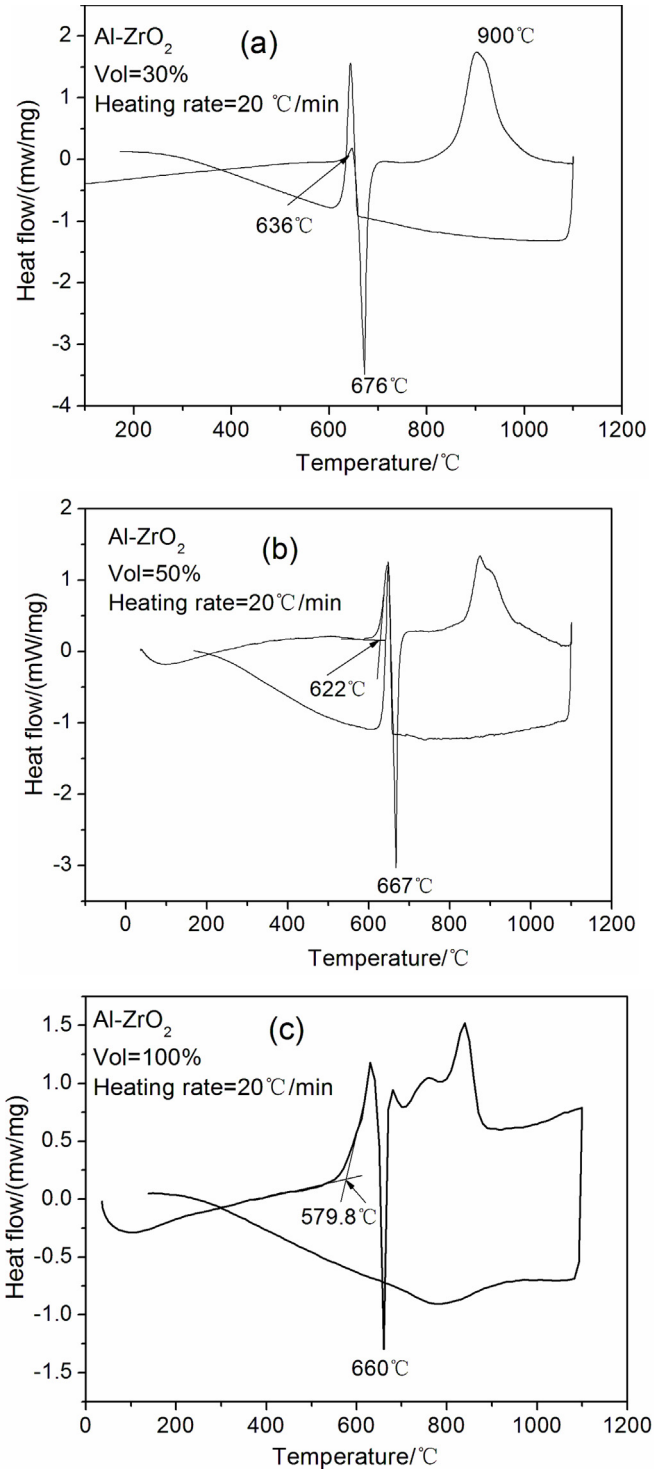


**Fig. 3.** DSC curves of the Al–$ZrO_2$ system with different reinforcement volume fractions of 30 vol.% (a), 50 vol.% (b) and 100 vol.% (c), respectively, obtained at a heating rate of 20 K/min.