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Self-propagating high-temperature synthesis of IrAl and its application to coating process

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Abstract

An IrAl intermetallic compound was fabricated by a self-propagating high-temperature synthesis (SHS) process. Single phase IrAl pellets were produced; however, the IrAl coatings produced, with the aid of numerical simulations, contained unreacted Ir and was found to have poor adhesion. Nevertheless, this study confirmed that IrAl coatings can be obtained using the SHS process.
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Keywords: IrAl intermetallic compound; Self-propagating high-temperature synthesis (SHS); Coating, Simulation

1. Introduction

In order to improve the efficiency and the performance of internal combustion engines, such as jet engines and gas turbines, a continual effort is being made in developing new components, which can be used at higher operating temperatures. To realize this, researchers' interests are directed at (i) developing new alloy systems with higher temperature capabilities, and (ii) developing new coating systems to be used on conventional metal substrates for increasingly higher temperature operations. Thus IrAl, which is an Ir-based intermetallic compound, is of great interest because of its high melting point, good mechanical properties and excellent oxidation resistance at elevated temperatures [1–4]. However, due to the large differences in the densities and melting points of Al and Ir, difficulties arise in fabricating a homogeneous and single phase compound by conventional methods, such as the arc melting process. In contrast, through the SHS process, intermetallic compounds can be produced at relatively low operating temperatures and in very short processing times. The economic benefits are widely recognized and, moreover, it is possible to fabricate products that only contain the targeted compounds [5–7].

Another practical interest is to apply the SHS process in coating fabrication, because SHS has promising characteristics, such as high coating yield and inherently low cost. For example, in physical vapor deposition processes the typical growth rate of Ir-based coatings is less than 10 μm/h and the deposition yield relative to the loss of raw material is normally less than 10% [8,9]. On the other hand, in the SHS process, the reaction is completed within seconds and, in principle, almost 100% of the reactant materials can be utilized for the coating layer.

In this investigation, the applicability of the SHS process to the production of IrAl, using Ir and Al powder mixture was studied. The study comprised two main parts. Firstly, attempts were made to obtain bulk IrAl using the conventional SHS process. A mixture of Al and Ir powder was inserted in a quartz crucible and

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the surface of the reactant was locally heated. Then the crystallinity and microstructural features of the synthesized products were investigated. Secondly, SHS was applied in coating fabrication with the aid of preliminary numerical simulations. The powder mixture was spread onto a preheated metal substrate surface, and was locally heated to initiate the exothermic reaction to form IrAl. The effects of preheated substrate temperature on the microstructural morphologies in the resulting coating layer were examined in terms of reaction yield and characteristics of the coatings produced.

2. Experimental procedure

The raw materials, aluminum powder (99.9% in purity, 75–150 μm in size or 99.95% in purity, 10 μm in size) and iridium powder (99.185% in purity, size ranging from several microns to 150 μm) were mixed to have the stoichiometric molar ratio of 1:1 = Ir:Al. Using this powder mixture, the measurement of the heat of reaction, Ir + Al → IrAl, was conducted by differential scanning calorimetry (DSC, Setaram-Setsys 24). Thirty to 60 mg of the powder mixture of Ir and Al was inserted into an alumina crucible and was heated from room temperature to 1073 K at the rate of 2 K/min in an argon atmosphere. Then the synthesis of bulk IrAl pellets and the formation of IrAl films were carried out. The combustion reactor used in this study is schematically shown in Fig. 1. For the fabrication of bulk IrAl pellets, the quartz crucible (ϕ: 20 mm, h: 25 mm) was filled with the reactant powder mixture and the top surface of the reactant was locally heated by a heating nichrome coil element (Fig. 1(a)) in vacuum (3.6 Pa). For the formation of IrAl films, the reactant powder mixture was spread on a plate-like Ni-based alloy substrate (Hastelloy C-276: Ni–16Cr–16Mo–5Fe–4W–2.5Co–1Mn–0.35V– 0.08S–0.01C in mass %), as shown in Fig. 1(b). Then one end of the specimen was locally heated so that the reaction propagated through it towards the other end. The specimens produced by these reaction syntheses were analyzed by X-ray diffractometry (XRD, MAC Science M18XHF) and scanning electron microscopy (SEM, JEOL JSM-5400).

3. Results and discussion

3.1. SHS of bulk IrAl

3.1.1. Heat of reaction measurement

In order for the SHS of IrAl to be carried out successfully, the heat of reaction must be high enough to sustain the propagation of the combustion wave and the reaction must initiate below the melting point of Al. The reaction kinetics of IrAl from unpacked (or unpressed) Ir and Al powder mixture was investigated by carrying out DSC measurements with various particle sizes and amounts of reactant powder mixture. It was found that while the reaction Ir + Al → IrAl was observed in all of the experimental runs at around 900 K (just below the melting point of Al), the molar heat of reaction varied depending on the particle size and the amount of reactant powder. These variations in the heat of reaction mainly result from the change in yield of reaction, in other words, the fraction of unreacted Ir and Al single phases, which were more or less always identified by XRD. The yield of reaction is increased by increasing the total amount of the reactant powder; however, if this amount exceeds a certain limit, the sensor of the DSC saturates and thus precise values of the heat of reaction cannot be measured. As shown in

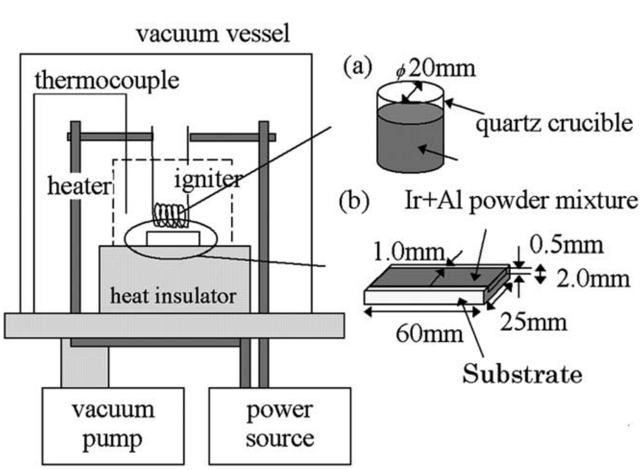

Fig. 1. Schematic representation of the combustion reactor system. Two types of specimens were prepared, in which reactants were (a) placed in a crucible, and (b) spread on a Ni-base alloy substrate.

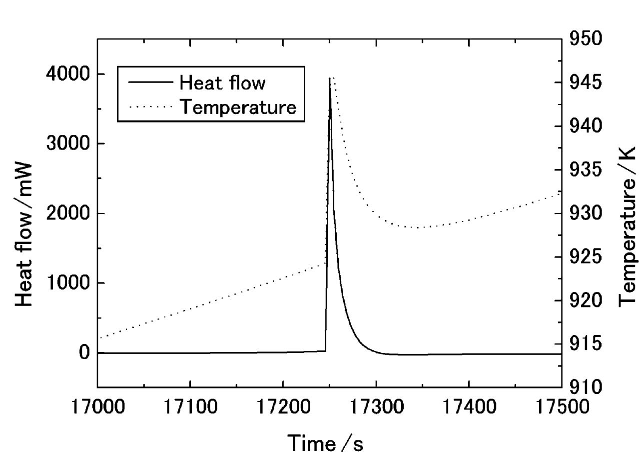

Fig. 2. Typical DSC profiles showing the change in heat flow and temperature as a function of time. The mass of Ir + Al powder mixture was 52.6 mg and Al powder size was less than 10 μm.

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