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Fe-Al intermetallic foam with porosity above 60 % prepared by thermal explosion

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ABSTRACT

The high porosity Fe-Al intermetallic foams have been successfully prepared by a simple and energy-saving process of thermal explosion (TE) approach from Fe-40 at.% Al elemental powders. The temperature profile, pore structure, phase composition and element distribution of Fe-Al foam were investigated. Due to the exothermic reaction, the temperature of sample increased rapidly from 637 °C to 981 °C in 9 s interval, which means that an obvious TE appears in the sintering process. The volume expansion of 88% was observed in heated sample, and the Fe-Al foam exhibited an interconnected pore structure with a high open porosity of 61%. XRD patterns showed that TE product contains Fe_2Al_5 and Fe while FeAl was evolved as dominant phase in final sintered materials. EDS results showed that Fe and Al distributed evenly in the final products.

1. Introduction

Intermetallics porous materials is a new type of inorganic porous materials between high temperature alloy and ceramic, it shows excellent performance with the common advantages of metal and ceramic materials because of the combination of metallic and covalent bonds [1]. Among the intermetallic compounds, porous Fe-Al alloys were considered as a substitute material for high temperature separation and filtration material, due to its low cost and density, high specific strength, excellent high temperature oxidation resistance and processability [2,3].

Nowadays, numerous methods have been utilized and optimized to synthesize porous FeAl materials, including reactive synthesis [4], vacuum sintering [5], plasma spraying [6], assisted sintering [7], and sintering-dissolution [8]. Gao et al. [4] fabricated porous Fe-Al intermetallics by element reaction sintering, and porous Fe-Al with a porosity of 42% was obtained when the pressure was set in 200 MPa. Chen et al. [5] prepared porous Fe-Al alloys with a porosity of 40.5% via vacuum segmented sintering, and pointed out that the Kirkendall effect is the significant factor of the pore formation mechanism. Recently, Karczewski et al. [7] synthesized Fe-Al porous materials through assisted sintering and crystalline oxalic acid (COA) as a foaming agent, and the permeability of sample increased significantly with additive of COA with a porosity of 48.5%. Meanwhile, residual traces of carbon were detected in the final product. However, the preparation of porous materials by the conventional powder metallurgy routes usually takes long sintering time, high energy consumption, limited porosity (<50%) and cause environmental pollution by added additive [4–6,9]. Therefore, it is necessary to develop facile and energetically efficient ways to prepare FeAl foam. Thermal explosion (TE) is a volumetric reaction that occurs when a reactant compact is heated rapidly in a furnace [10], it is a typical mode of combustion synthesis (CS) reaction, which is different with conventional sintering or explosion [11,12]. It offers an attractive method for preparing intermetallic compounds, ceramics, and composites with a high porosity in short time [13,14], To date, such as NiTi [15], Ti_2AlC [16] and NiAl/WC [17] have been successfully synthesized through TE.

In this paper, porous Fe-Al intermetallics were prepared by a simple and rapid thermal explosion reaction. The temperature curve was proposed in the thermal explosion process, and the pore

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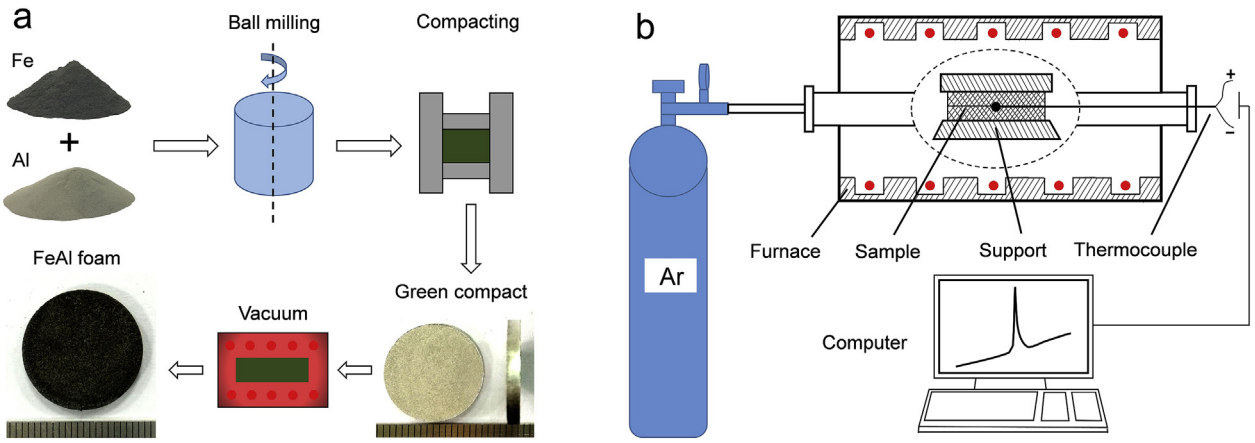

Fig. 1. Schematic illustration of the processing to prepare FeAl foam: (a) flow chat and (b) monitor the temperature of the sample.

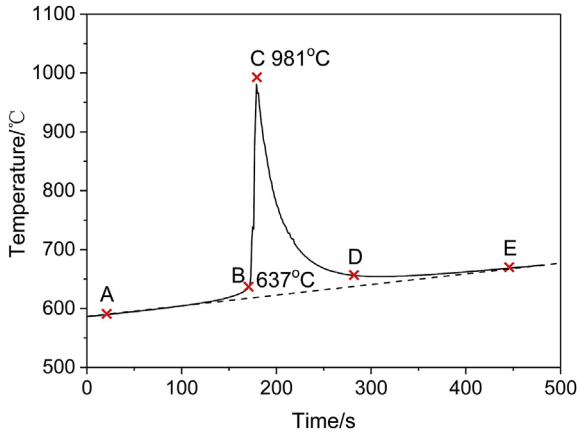

Fig. 2. Time-temperature curve of the Fe-Al compacts during sintering.

structure, phase composition and element distribution of porous Fe-Al were investigated.

2. Experimental procedure

Fig. 1 showed the preparation process of the FeAl foam. The chemical elements of Fe (38.5 μm, 98.0% purity) and Al (38.5–74 μm, 99.9% purity) powders were used as starting raw materials, and the powder mixtures were weighed with the molar ratio of Fe-40 at.% Al, which exhibited a desired comprehensive properties [18,19]. The powders were wet mixed using ethanol as the medium in a planetary ball mill (QM-ISP2-CL, China) for 4 h (450 r/min), and then dried at 50 °C for 24 h. Compacted cylindrical discs with diameter of 16 mm and thickness of 3 mm were prepared by cold-pressing under a pressure of 200 MPa. Subsequently, the entire green compact was heated to 700 °C for 30 min and 1000 °C for 1 h in a tube furnace (OTF-1200X, China) under vacuum conditions (7.6×10^{-3} MPa), and the heating rate was 10 °C/min. In order to determine the occurrence of the TE, the same thermal program was repeated in a same furnace with a constant flow of argon (0.1 MPa, 100 ml/min). A platinum-rhodium thermocouple with a diameter of 100 μm (WRP-S, with a frequency of 100 Hz) was placed between the two samples to monitor the temperature of the sample, which was used to illustrate the temperature-time curve (Fig. 1b). The entire reactants are heated simultaneously, and once a sharp rise in temperature is observed, which means that the thermal explosion (TE) occurred [11].

The porosity of the porous FeAl materials was measured by the Archimedes method [20,21]. The differential scanning calorimeter (DSC) was detected on a differential thermal analysis instrument (Netzsch STA449F3, Germany) to determine the nature of the TE reactions, a constant flow of argon was maintained during heating to protect the samples against oxidation, and the samples were heated at a constant rate (10 °C/min) up to 800 °C. Phase identification was carried out by X-ray diffraction (XRD) on a Bruker D8ADVANCE machine with Cu target (λ = 0.15406 nm). Microstructures were characterized by optical microscopy (Olympus) and Scanning Electron Microscopy (SEM, Quanta 250) equipped with UANTAX400 Energy Dispersive Spectrometer (EDS) to carry out elemental analysis. A thin layer of gold was sputtered on surface of the samples before SEM observation.

3. Results and discussion

Fig. 2 shows the dynamic time-temperature curve of Fe-Al samples during sintering. It can be seen that the sample temperature increase slowly with the heating rate of 10 °C/min (dotted line). Subsequently, the sample temperature climb rapidly from 637 °C to 981 °C, which means the sample was ignited at point B and reached to the maximum temperature of point C (See

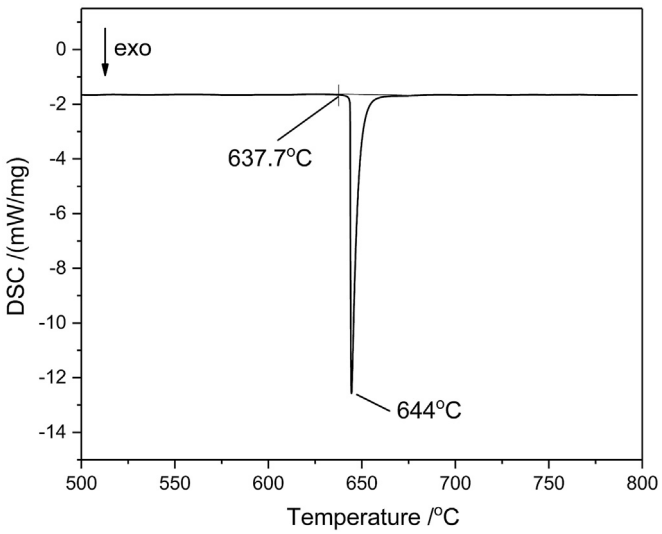

Fig. 3. DSC profile of Fe-40 at.% Al sample.