CAPILLARY PROCESSES DURING THE FORMATION OF POROUS NI-AL MATERIALS IN THE SHS MODE[1]

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Ni-Al intermetallic alloys are characterized by the combination of such unique properties as heat resistance, strength, ductility and a number of other important physical and chemical properties. They are widely used in mechanically stressed elements of aerospace, heat-energy and chemical equipment operating in corrosive high-temperature media. Porous materials based on such alloys are very promising for chemically resistant filters, high-temperature heat exchangers and infrared emitters of gas burners. Practical application of the latter is often restricted by the complexity of preparing NI-AL materials with the necessary combination of phase composition and pore morphology.

The most efficient method for obtaining porous intermetallic compounds is self-propagating high-temperature synthesis (SHS). SHS provides an autothermal reaction for the synthesis of compounds and sintering of materials in a special powder reaction mixture in a one stage. A peculiarity of SHS is a strong dependence of the process dynamics on the effects of capillary redistribution of melting components in a reaction mixture: melt spreading over the surface of solid particles, Marangoni convection. These effects have not yet been fully studied in detail.

The goal of this work is to experimentally study the combined effect of the initial structure of a mixture and capillary processes on the reaction dynamics and the product formation during the SHS of Ni-Al materials. The initial structure of the reaction mixture was varied by changing its porosity (P = 10÷60%), the concentration of Al (CAl = 13÷ 0 wt.%), the diameter of Ni, Al particles (d Ni = 10÷100 µm, d Al = 10÷1000 µm) and the form of Al (particles, plates). The reaction conversions were recorded with high-speed video at the macro-and micro-levels of the reaction mixture, and were controlled by thermocouple measurements, hardening operation, and the physical and chemical analysis of the products.

The main results:

- The active conversion of the mixture was shown to take place in the SHS wave when Al starts melting. Two qualitatively different SHS modes were found, which depended on the particle size ratio of the components. Mode 1: d Al >> d Ni . The reaction mixture is a system of large Al particles surrounded by porous layers of small Ni particles. At the macroscopic level, conversions are divided into two consecutive stages. Fast dissolution of Ni particles in the Al melt, primary capillary spreading of the liquid solution through the Ni layer and an exothermic heterogeneous reaction simultaneously take place at the first stage (t≈1÷3 ms). Dissolution occurs with the participation of Marangoni convection, which stimulates the transport of a part of the Ni layer from the Ni-AL contact boundary to the melt. At the second stage, a relatively slow (t≈100÷200 ms) capillary redistribution of the liquid solution over the Ni layer and the system overreaction are observed. The stepwise temperature SHS-wave profile, which corresponds to the microscopic stages of the system transformation, is recorded at the macroscopic level. By varying porosity, the maximum SHS propagation velocity is observed for the conditions when the initial volume of pores and aluminum is equal. The pores of the synthesized Ni-Al materials are mainly isolated: the shape of large pores follows the contours of initial Al particles, and the size of small pores is equal to the diameter of initial Ni particles. Mode 2: d Al ≈ d Ni . The reaction mixture is a relatively homogeneous mixture of Ni and Al particles. At the microscopic level, there is a one-stage process of spreading liquid Al particles over the Ni surface (t≈1ms) followed by the heterogeneous reaction. A monotonic temperature profile of the SHS wave is recorded at the macroscopic level, and the wave propagation velocity monotonically increases with decreasing porosity. In the region of Π > 20%, open porosity of the final product is observed.

- The SHS of the laminate material was conducted in the form of soldered plates from a dense Ni-Al alloy (C Al = 16 wt.%, the plate thickness was 1.5 mm), separated by open voids. The synthesis was conducted in a system of alternating layers of dense Al and porous powder layers of Ni. The self-sustaining reaction process consisted of consecutive stages of Al melting followed by melt spreading over Ni layers and an exothermic reaction. The material obtained can be used as highly permeable heat-resistant heat exchangers and infrared emitters.

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