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Investigation of the aluminum nitride formation during the aluminum nanopowder combustion in air

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Abstract

The phase formation sequences, intermediate and final products of aluminum nanopowder combustion are studied. The experiments were performed in the Budker Institute of Nuclear Physics, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, at the "Precision Diffractometry II" station (SR beamline No. 6 of the VEPP-3 electron storage ring). The main combustion product was found to be aluminum nitride. In the combustion of aluminum nanopowder aluminum γ -oxide is the first to form, and aluminum nitride arises next. The formation of aluminum nitride probably occurs by successive replacement of oxygen by nitrogen from the aluminum oxide. The use of synchrotron radiation with high photon flux made it possible to determine with moderate time resolution the sequence of stages of formation of crystalline products during combustion of the aluminum nanopowder.

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Keywords: nanopowder; aluminum; combustion; synchrotron radiation; combustion products; aluminium nitride; phase formation sequence.

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1. Introduction

According to existing conceptions [Korshunov et al. (2010)], during Al nanopowder (NP) combustion the formation of an independent crystal phase of aluminum nitride assumes interaction of aluminum only with nitrogen, in a certain volume in the presence of oxygen within a short period of time. Stabilization of nitride can be connected with kinetic suppression of oxygen diffusion through a nitride layer caused by thermodynamically allowed process of aluminum nitride oxidation by air oxygen. Earlier thermodynamic calculations showed that aluminum nitride can appear as an intermediate product during powdery aluminum combustion, but it has to be oxidized by air oxygen and does not remain in the final products. Reaction of nitride formation in air with high content of aluminum nitride in the final products becomes possible only due to aluminum nanopowder (NP Al). Thus, aluminum nitride synthesis by means of aluminum nanopowder combustion in air seems to be an alternative way of AlN production [Zakorzhevskii et al. (2002) and Wilmanski et al. (2014)].

The aim of this work was to elucidate phase formation sequence during aluminum nanopowder combustion in the air using time resolved X-ray diffraction of synchrotron radiation.

2. Experimental procedure

NP of aluminum was obtained by electrical explosion of aluminum wires, aerogel density is 0.08 g/cm^3 . During passivation, additives air is formed "argon coats" for oxygen, nitrogen and water. Wherein the bulk density of NP increases and reaches $0.15 - 0.20 \text{ g/cm}^3$. If not passivated, aluminum NP being stored forms and sintered agglomerates. The bulk density and the degree of agglomeration significantly affect the combustion rate and composition of the reaction products: the content of aluminum nitride reduces, and the unburned aluminum fraction increases. Compaction of NP aluminum ($0.5 - 1.0 \text{ kg/cm}^2$) reduces flammability and sintering.

Aluminum NP produced by an electric explosion of conductors in argon was studied. The NP was produced using an UDP-4G installation developed at the Tomsk Polytechnic University which provides an aluminum NP yield of 50 g/h [Gromov and Teipel (2014)]. The diameter distribution of the resulting powder particles is close to a lognormal one with a maximum of 120 nm and an asymmetry to large particle size (Fig. 1). The content of metallic impurities did not exceed 0.2% . The NP was passivated by small addition of air, after which it remained stable when heated in air up to 400°C .

Under condition of thermal explosion ($2200-2400^\circ \text{C}$), aluminum nitride is formed in the gas phase in the second stage of combustion and is stabilized due to the endothermic process, followed by crystallization into a solid phase (exothermic process) [Il'in et al. (2011)]. The growth of crystals during combustion of aluminum NP in air occurs toward the heat flow, which is consistent with the classical concepts of crystal growth [Laudise (1970)]. The time of combustion of aluminum NP and subsequent crystallization of the product was $\sim 1 \text{ min}$. The combustion products of the aluminum NP obtained in the mode of thermal explosion were analyzed by Auger electron spectroscopy (ESO-5UM). It was found that the surface consisted of aluminum (42%), nitrogen (28%), and oxygen (30%), which corresponds to the oxidized surface of aluminum nitride.

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