ISSN 1061-3862, International Journal of Self-Propagating High-Temperature Synthesis, 2007, Vol. 16, No. 2, pp. 62–69. © Allerton Press, Inc., 2007.

SHS Reactions in the NiO–Al System: Influence of Stoichiometry[1]

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Received November 22, 2006

Abstract—Thermite reactions in the NiO–Al system have been studied. In addition to the case when the stoichiometry is set up to produce metallic nickel and alumina, we studied the case when Al is added in excess in order to react with the Ni produced through the reduction of nickel monoxide with Al to produce various nickel aluminides. As thermite reactions are highly exothermic, in order to provide a better understanding of the reactions, alumina has been added to the green mixture to reduce the reaction rate and overall exothermicity, in amounts corresponding up to 50% of the overall heat capacity of the sample.

Keywords: combustion synthesis, SHS, nickel aluminides, influence of stoichiometry

PACS numbers: 81.05.Je, 81.05.Mh, 81.16.Be, 81.20.Ka

DOI: 10.3103/S1061386207020021

INTRODUCTION

Thermite reactions are well known for being highly exothermic, and the adiabatic temperature often reaches 3000 K. Indeed, Al has an extremely high affinity to oxygen and it can therefore be used to reduce the most of metal oxides. As an example, we previously studied [1] the basic thermite reaction of Al with nickel monoxide:

$$3NiO + 2Al \longrightarrow 3Ni + Al_2O_3. \quad (1)$$

As expected, the products of such a reaction are liquid, if not gaseous. Consequently, such a reaction has a few drawbacks, including intense sputtering, and the final products could not therefore be retrieved, except in the form of a powder completely dispersed inside the reaction chamber. Moreover, the reaction may also be incomplete, as the sputtering may occur slightly ahead of the reaction zone, mainly due to Al boiling, thus separating the reactants before they react.

These drawbacks can easily overcome by using an inert diluent. Diluent is a substance added to the system that will not take part in the reaction, and therefore will not bring any additional enthalpy into the system. On the contrary, its presence will increase the overall heat capacity and, the total amount of heat brought by the reaction enthalpy remaining constant, the final temperature will therefore decrease, according to the well known equation:

$$\Delta H_f^\circ = \int_{T_{in}}^{T_{fin}} C_p dT. \quad (2)$$

In [1], we studied the effect of added Al_2O_3 on the temperature reached and on the structure of burnt samples. Without added alumina, the samples were completely destroyed by sputtering. When the added alumina represented 20% of the overall heat capacity (hc) (or 20 hc % Al_2O_3 for short), boiling and dispersion of the sample could be avoided, although the sample underwent a complete melting. Finally, for higher hc % Al_2O_3 values, the structure of the sample could be preserved, and the phase segregation could be partially suppressed, especially at 40 hc % Al_2O_3.

This study will focus on the influence of stoichiometric ratio, and Al will be added in excess relative to Eq. 1, and we will consider the following reactions:

$$3NiO + 3Al \longrightarrow AlNi_3 + Al_2O_3, \quad (3)$$

$$15NiO + 19Al \longrightarrow 3Al_3Ni_5 + 5Al_2O_3, \quad (4)$$

$$3NiO + 5Al \longrightarrow 3AlNi + Al_2O_3, \quad (5)$$

$$6NiO + 13Al \longrightarrow 3Al_3Ni_2 + 2Al_2O_3, \quad (6)$$

$$3\ NiO + 11Al \longrightarrow 3Al_3Ni + Al_2O_3. \quad (7)$$

[1] The text was submitted by the authors in English.