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SHS of High-Purity MAX Compounds in the Ti–Al–C System

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Abstract—During the synthesis of MAX phases using combustion synthesis (or Self-Propagating High-temperature Synthesis), the main drawback is the presence of binary phases, and especially the simple MX carbide, when X = C. Our experiments were designed in order to check whether the cooling rate of the sample immediately after synthesis might play a key role for obtaining samples with low-level carbide contents. In the best conditions, a TiC content of about 2% only has been observed. A systematic study on the direct effect of the cooling rate on the final composition has then been conducted, and confirms that high cooling rates allow the synthesis of high-purity MAX phases in the Ti–Al–C system.

Keywords: SHS, MAX compounds, Ti–Al–C system

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INTRODUCTION

Since their discovery in the 60s by Jeitschko, Novotny et al. (see e.g. [1]), the phases presently known as the MAX phases have drawn little attention by the scientific community, until some a decade ago, when they became the subject of intensive research, mainly at Drexel University [2–4].

It would be unfair, however, to disregard earlier work performed in the field of SHS, which presented some very promising results using direct synthesis from the elements. Amongst the researchers involved in such a study, one can find the people working at the Faculty of Materials Science and Ceramics in Cracow (Poland), whose first results were published almost 20 years ago [5–9]. They were followed by others in various countries [10, 11] using various techniques to either improve the purity of the final phase or to decrease the remaining porosity.

MAX phases are ceramic materials, for which a new class has been created, the so-called “nanolamellar” ceramics. Indeed, within its crystal structure, at a truly nano-scale, the ceramic is made of a succession of planes where the dominant atomic bond is alternatively a strong metal-non metal bond or a weaker metal-metal bond. This particular succession of chemical bonds yields a material made of strong planes weakly linked to each other in their perpendicular direction.

As a consequence, these ceramics display very unusual properties, intermediate from the ones of metals and those of classical ceramics. Their thermal, chemical, and electrical properties are very similar to those of the corresponding carbides/nitrides: high thermal diffusivity, electrical conductivity, and good oxidation resistance. However, their mechanical properties are very peculiar. Like ceramics, they do present a high bulk modulus, even under high temperature, but at the same time, they have a much lower hardness, exhibit a good resistance to thermal shocks, and, finally, are machinable.

Early work related to these phases using SHS has been, if not completely disregarded, at least overlooked. One of the reasons may be a high residual phases content, around 30%, found in the final product, especially TiC, when synthesizing Ti_3SiC_2, Ti_3AlC_2, Ti_2AlC [15]. Other processes proposed around the same time, however, would systematically be more complex and include a purification step, which could have been proposed as a complement of SHS as well [16]. The residual TiC content at that time was about 5%.

SHS remains an attractive process to synthesize these materials, especially for its simplicity, low energy consumption, and low facility cost. Recent advances to better understand the reaction kinetics, with the final aim of gaining a good control on the final product [17, 18] have then to be pursued.

This paper presents the results obtained to improve the purity of the Ti_2AlC MAX phase obtained by SHS by a control of various parameters, including the initial powder stoichiometry and heat losses. These results help to understand why some authors may find very low remaining TiC [18] while others have about 30% of this residual phase [15].