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Synthesis and thermal stability of Cr_2AlC

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Abstract

A new reaction route with $AlCr_2$ and C as starting materials has been developed to produce Cr_2AlC. A Cr_2AlC bulk ceramic was achieved by hot pressing the $AlCr_2$ and C powders at 1400 °C with 20 MPa for 1 h in Ar. The mechanism to form Cr_2AlC in a temperature range of 1050–1400 °C was studied. It was confirmed that Cr_2AlC is formed directly by a reaction between C and $AlCr_2$. The reaction process, phase composition and microstructure were characterized with differential thermal analysis, X-ray diffractometry and scanning electron microscopy. The produced Cr_2AlC ceramic is stable up to 1500 °C in an Ar atmosphere, but decomposes into Al_8Cr_5 and $Cr_{23}C_6$ above 1500 °C.

Keywords: Cr_2AlC; Carbides; Hot pressing; Microstructure; Thermal properties

1. Introduction

The Cr_2AlC ternary carbide displays both ceramic and metallic behaviour. This MAX phase material exhibits a combination of attractive properties.[1–5] It has a high strength and yet is relatively ductile. The material is a good electrical and thermal conductor. Due to its oxidation and corrosion resistance as well as to thermal shock resistance, it can be used at high temperatures and in aggressive environments. Unlike conventional ceramics, Cr_2AlC is easily machinable.

The mechanical and electrical properties, together with the self-lubricity of Cr_2AlC make this material not only a suitable alternative coating to expensive metallic plating on electrical connectors, but also a good candidate for some applications where graphite or graphite–metal composites are widely used such as bipolar plate in fuel cells, pantographs and electrical brushers. In addition, with the combination of high strength, non-susceptibility to thermal shock, and high temperature oxidation and corrosion resistance, Cr_2AlC is also considered as a promising candidate for structural ceramic components, electrodes, and gas burner nozzles.

So far, several methods have been used to synthesize Cr_2AlC ceramics from mixtures of Cr/Al/C, Cr/Al_4C_3/C, or $CrC_{0.5}$/Al powders including mechanically activated hot pressing,[4] hot isostatic pressing,[6] hot pressing,[3,7,8] and pulse discharge sintering.[9,10] One of the suggested reaction mechanisms to form Cr_2AlC, involves a reaction route between C and an intermediate phase, viz. $AlCr_2$ during sintering.[4,7,11] However, no direct experimental evidence has been provided yet to support such a reaction route.

In this work, $AlCr_2$ was used as a starting material to produce Cr_2AlC. The advantages of a direct synthesis of Cr_2AlC from C and $AlCr_2$ are obvious: (i) the reaction process is simple and more controllable for an $AlCr_2$/C mixture compared with that for the Cr/Al/C or Cr/Al_4C_3/C mixtures upon sintering, (ii) the formation of impurities such as Al_4C_3, Cr_7C_3 and Cr–Al phases in the final product may be avoided, and (iii) pure Cr_2AlC powders and/or bulk materials can be produced on a large scale. The synthesis of a Cr_2AlC ceramic from a mixture of C and $AlCr_2$ will be reported. Results of detailed composition and microstructure analysis of the final product will be presented.

For high temperature applications, some properties for Cr_2AlC have been studied extensively,[1–4,8,9] however, its thermal stability is still unknown. It is well known that MAX phase materials may decompose at very high temperatures. For example, Ti_3SiC_2 becomes unstable at temperatures above 1400 °C in vacuum or Ar atmosphere,[12–14] Ti_3AlC_2 decomposes at above 1400 °C in vacuum atmosphere,[15,16] and Ti_2SnC decom-

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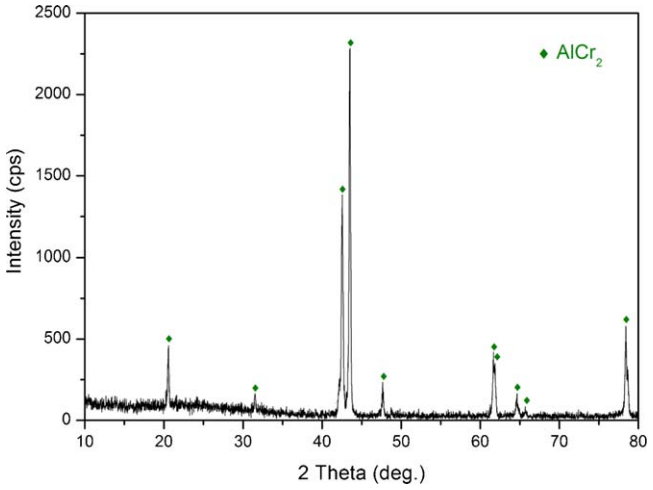

Fig. 1. XRD pattern of 2Cr/1.2Al mixture after pressureless sintering at 1100 °C for 1 h in Ar. ICDD card number for $AlCr_2$ is 03-065-6360.

poses at above 1200 °C in Ar atmosphere[17] and at 1250 °C in vacuum atmosphere,[18] respectively. In this study, the thermal stability of Cr_2AlC was investigated and the results were presented.

2. Experimental procedures

Powders of Cr (particle size <75 μm, 99.5 wt.% purity), Al (particle size <5 μm, 99.5 wt.% purity) and C (graphite, particle size <45 μm, 99.5 wt.% purity) were used as the starting materials.

To produce $AlCr_2$, the Cr and the Al powders with a mole ratio of 2:1.2 (denoted as 2Cr/1.2Al) were mixed for 5 h and then pressurelessly sintered at 1100 °C for 1 h in an Ar atmosphere. Next, the sintered $AlCr_2$ sample was pulverized to a powder and sifted with a 200-mesh sieve.

Subsequently, the designed Cr_2AlC material was prepared from the $AlCr_2$ and C powders with a molar ratio of 1:1 (denoted as $AlCr_2$/C) by pressurelessly sintered at 1050–1400 °C for 15 min in an Ar atmosphere. This mixture was also hot-pressed at 1400 °C for 1 h with 20 MPa in Ar to synthesize a Cr_2AlC bulk ceramic.

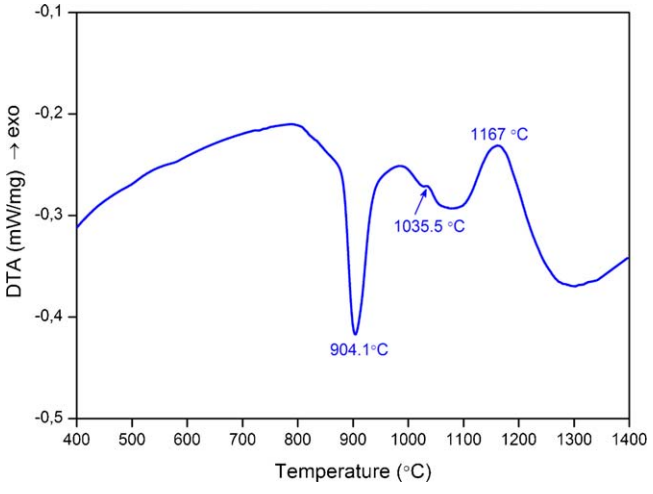

Fig. 2. DTA curve recorded of an $AlCr_2$/C mixture with a heating rate of 15 °C/min in Ar.

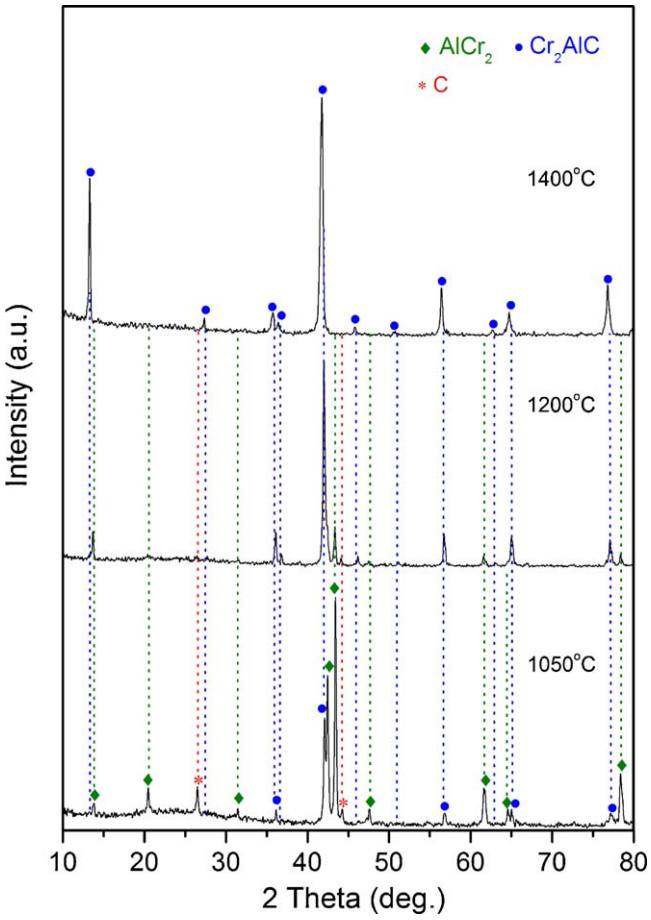

Fig. 3. XRD patterns of $AlCr_2$/C powders after pressureless sintering for 15 min in Ar at 1050 °C, 1200 °C, and 1400 °C, respectively. ICDD card numbers for Cr_2AlC, $AlCr_2$, and C are 01-089-2275, 03-065-6360, and 01-075-1621, respectively.

The phase composition and microstructure of the synthesized materials was identified with X-ray diffractometry (XRD) analysis using a D/Max 2200 PC diffractometer (Tokyo, Japan) operating with Cu Kα radiation, scanning electron microscopy (SEM) using a JEOL JSM 6500F scanning electron microscope (Tokyo, Japan)) equipped with a NORAN System 7 X-ray Microanalysis (XMA) including an Ultra Dry silicon drift detector (SDD) 10 mm^2 (Thermo Scientific, USA), and optical microscopy (OM) using a Neophot 30 optical microscope (Carl Zeiss, Germany).

Differential thermal analysis (DTA) was performed with the $AlCr_2$/C mixture under flowing Ar in a thermal analysis instrument (Netzsch STA409C, Germany) with a heating rate of 15 °C/min in a temperature range of 25–1400 °C. DTA was also used to investigate the thermal stability of Cr_2AlC under flowing Ar in a temperature range of 25–1600 °C with a heating rate of 15 °C/min. The decomposed sample was characterized by XRD, SEM and XMA.