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Original Research Paper

Combustion synthesis of $(Mo_{1-x}Cr_x)Si_2$ (x = 0.00–0.30) alloys in SHS mode

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ABSTRACT

Combustion synthesis was adopted to successfully synthesize molybdenum–silicon–chromium (Mo–Si–Cr) alloys by the mode of self-propagating high-temperature synthesis (SHS). The experimental study of combustion synthesis of Mo–Si–Cr alloys was conducted on elemental powder compacts. Powder compacts with nominal compositions including $MoSi_2$, $(Mo_{0.95}Cr_{0.05})Si_2$, $(Mo_{0.90}Cr_{0.10})Si_2$, $(Mo_{0.85}Cr_{0.15})Si_2$, $(Mo_{0.80}Cr_{0.20})Si_2$, $(Mo_{0.75}Cr_{0.25})Si_2$ and $(Mo_{0.70}Cr_{0.30})Si_2$ were employed in combustion synthesis experiments. The combustion mode, combustion temperature, flame-front propagation velocity and product structure were investigated. The results showed that Mo–Si–Cr alloys were synthesized by an unsteady state combustion mode with a spiral-trajectory reaction front. The peak combustion temperature reduced with the addition of Cr to Mo–Si system. The flame-front propagation velocity decreased with an increase in Cr content of the powder compact. The X-ray diffraction (XRD) results showed that the crystal structure of the combustion product changed from Cll_b-type structure $(Mo_{0.90}Cr_{0.10})Si_2$ to C40-type structure $(Mo_{0.85}Cr_{0.15})Si_2$ with increase in Cr content of Mo–Cr–Si alloys. The intensities of diffraction peaks of the C40-type phase gradually increased with increase in Cr content.

1. Introduction

$MoSi_2$ is a promising candidate material for high-temperature structural application owing to its high melting point (2303 K), excellent oxidation resistance at high temperatures (>1473 K), relatively low density (6.24 g/cm^3), lower coefficient of thermal expansion (8.1×10^{-6} K^{-1}), high thermal and electrical conductivities [1–3]. However, it has low fracture toughness at room temperature (2–3 MPa.m$^{1/2}$), low strength at high-temperature (>brittle–ductile transition temperature) and poor oxidation resistance at about 500 °C (Pesting). Due to these disadvantages, its use in structural applications has been limited. Thus the key material issue is to improve its ductility at room temperature and strength at high temperature [2–4].

In metals, alloying is a major approach employed to increase room temperature fracture toughness. However, this has not been the case for structural ceramics because of the iono-covalent bonding [1]. Alloying approaches to improve the toughness of structural silicides are, however, much more promising, due to the metallic–covalent bonding of these materials [1–3]. The effects of W, Ti, Re, Nb, Ta, Cr, Zr, V, and Al alloying additions on the microstructure and mechanical properties have been reported [1–8]. Yi et al. have prepared $MoSi_2$-based alloys by the arc melting process from high-purity metals. The EDS analysis showed that Fe, Co, and Ni had no solid solubility in as-cast $MoSi_2$, while Cr, V, Ti, and Nb exhibit limited solid solubility, and solid solubility of Cr was determined to be 1.4 ± 0.7 at.% [7]. However, Frankwicz et al. found that the solid solubility of Cr in $MoSi_2$ was about 3 at.% [7].

Harada et al. have prepared $MoSi_2$, $(Mo_{0.985}Cr_{0.015})Si_2$, $(Mo_{0.97}Cr_{0.03})Si_2$ and $(Mo_{0.9}Cr_{0.1})Si_2$ button ingots, using a tri-arc furnace. The melting procedure was repeated six times [6]. Their results show that microhardness decreases slightly in the $C11_b$-type region; however, in two phase region of Cll_b + C40 -type, the microhardness increases gradually with chromium content [6]. Single crystals of the nominal compositions of $MoSi_2$ and $(Mo_{0.97}Cr_{0.03})Si_2$ were grown using optical floating-zone furnace by Inui, Ishikawa, and Yamaguchi [5]. The Cr additions decreased the yield strength at low temperatures (below 800 °C) and increased the yield strength at high temperatures (above 1300 °C) [5].

Though $MoSi_2$ has excellent oxidation properties at high temperatures, it disintegrates catastrophically (termed as "Pesting") during oxidation at low temperature (400–600 °C) [9–11]. From thermodynamic considerations, the third element X with a larger affinity to oxygen than Si (i.e. Al, Ti, Zr, and Y) is oxidized selectively at grain boundaries. In the case when the volume expansion during internal oxidation is small, the pesting phenomenon is suppressed [9–12]. The specimens of $MoSi_2$, $(Mo_{0.90}Cr_{0.10})Si_2$ and $(Mo_{0.85}Cr_{0.15})Si_2$ were prepared by sintering in hydrogen at 1615 °C. Oxidation tests were performed for 456 h (three weeks)

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