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Microstructure and mechanical properties of molybdenum silicides with Al additions

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Abstract

Several molybdenum silicides alloys with different aluminum additions were produced by the arc-cast method. Microstructure observed in the alloys presented a variation of the precipitated second phase respect to the aluminum content. Evaluation of the compressive behavior at high temperature of the alloys shows an important improvement in its ductility, approximately of 20%. Fracture toughness was increased proportionally with Al content. In addition at room temperature the alloys show a better mechanical behavior in comparison with the sample unalloyed. In general, Al additions result to be a good alternative to improve the resistance of these intermetallic alloys. The results are interpreted on the base of the analysis of second phase strengthening.

Keywords: Mechanical properties; Molybdenum silicides; Hardness; Fracture toughness; Intermetallic alloys

1. Introduction

Significant progress has been reached during the last century in applications for high temperature materials in the aerospace industry, energy, materials processing and many other fields. Essentials to the success of these projects are the new materials such as the intermetallic compounds, which can work at marginal temperatures and stresses under extreme environments. Many intermetallic alloys have been studied extensively, such as nickel aluminides, titanium aluminides, and transition metal disilicides as potential high temperature candidates [1–2]. Intermetallic compounds, specially the silicides, offer the desired properties for high temperature structural applications. The silicides are a new class of materials considered as promissory in structural applications at high temperatures as for aerospace engineering as energy industry due to the combination of high melting point, relative low density and good corrosion resistance [3]. The $MoSi_2$ intermetallic compound and specially $MoSi_2$-base composites are materials used as refractory, wear and corrosion resistant materials, however the main disadvantage of the $MoSi_2$ is its low fracture toughness at room temperature and pest corrosion effect. The before characteristics can be enhanced through the alloying with other elements or forming composites. Several elements has been alloyed with the goal of enhance the mechanical properties of silicides such as V, Cr, Nb, Al, W, Re [4] and B [5] with good results. It is reported that Mo-rich Silicides Boron alloyed posses high melting point (up to 2000 °C), good toughness at room temperature and great creep resistance at elevated temperature, however oxidation problems between 650 and 750 °C has been reported, therefore, the application of an Al pack cementation coating is needed [5]. In addition it also has been found that Al additions induces a crystal structure transformation from C_{11b} to a C40 which enhances its high temperature properties [4].

Until now many studies has been performed on Molibdenum silicides [6–11] and specifically the molybdenum disilicides [3–4,12–13], remaining compounds such as Mo_3Si without high attention. In the present investigation, we study this kind of intermetallic compound with A15 structure which has very limited information in such a way that the purpose of the current work is to develop a systematic study of the characterization of molybdenum silicides alloys with Al additions, correlating the effect of

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the microstructure with their mechanical properties for possible structural applications.

2. Experimental procedure

The alloys were produced by the arc-melting technique under an argon atmosphere (99.999% purity) with a constant 75 at.% Mo composition and Aluminum additions ranging from 8 to 16 at.%. Due to the higher grade of aluminum evaporation and based in weight losses calculations, an extra amount of this element was added (up to 1 at.%). The alloys were drop-cast into water-cooled copper molds with a diameter of 12.5 mm. After that, the specimens were annealed in a vacuum of 10^{-4} Pa for 24 h at 1400 °C, and then furnace cooled. After metallographic polishing the specimens were etched with Murakami's reagent during 1–2 s and observed in an optical microscope. The measurement of the area fraction was performed using the IPA (Image Processing Analysis) software of the equipment. Qualitative chemical analysis of the microstructures was performed in a scanning electron microscope equipped with an energy dispersive spectroscopy system (EDS) with internal standards for determining the Mo:Si:Al ratios, then X-ray diffraction analyses were carried out in PHILIPS XRG-3100 equipment. Hardness test were realized in a Leco 300 microhardness tester with a load test of 200 g and a holding time of 15 s. Compression specimens with dimensions of 2 mm × 2 mm × 4 mm were also machined and compressed in an Instron 4501 testing machine at 1400 °C in argon atmosphere at a compression rate of 10^{-3} s^{-1}, the machine have an internal strain gage to measure de displacement of the compression rods.. Fracture toughness tests were developed based on the ASTM E399 [14] standard using a notched sample (three point bending procedure).

3. Results and discussion

3.1. Microstructure

Fig. 1a–c shows the different microstructures obtained in the alloys under study related to the Al content after annealed for 1 day at 1400 °C in vacuum atmosphere. In this series it can be observed the formation and evolution of a second phase, both were identified first by EDAX (energy disperse X-ray analysis) and then by X-ray diffraction analysis as Mo_3Al_8 into the matrix of Mo_3(Si, Al). According to the micrographs in Fig. 1a, the Mo_3Al_8 phase precipitates in the alloy containing 8 at.% Al and such phase is softer than the matrix of Mo_3(Si, Al) being the last one the fragile phase located in the interdendritic zone as the microhardness tests shows. In addition, it is observed that the area fraction of the Mo_3Al_8 phase (dendritic zone in Fig. 1a and b) grew up proportionally with the increment of the Al in

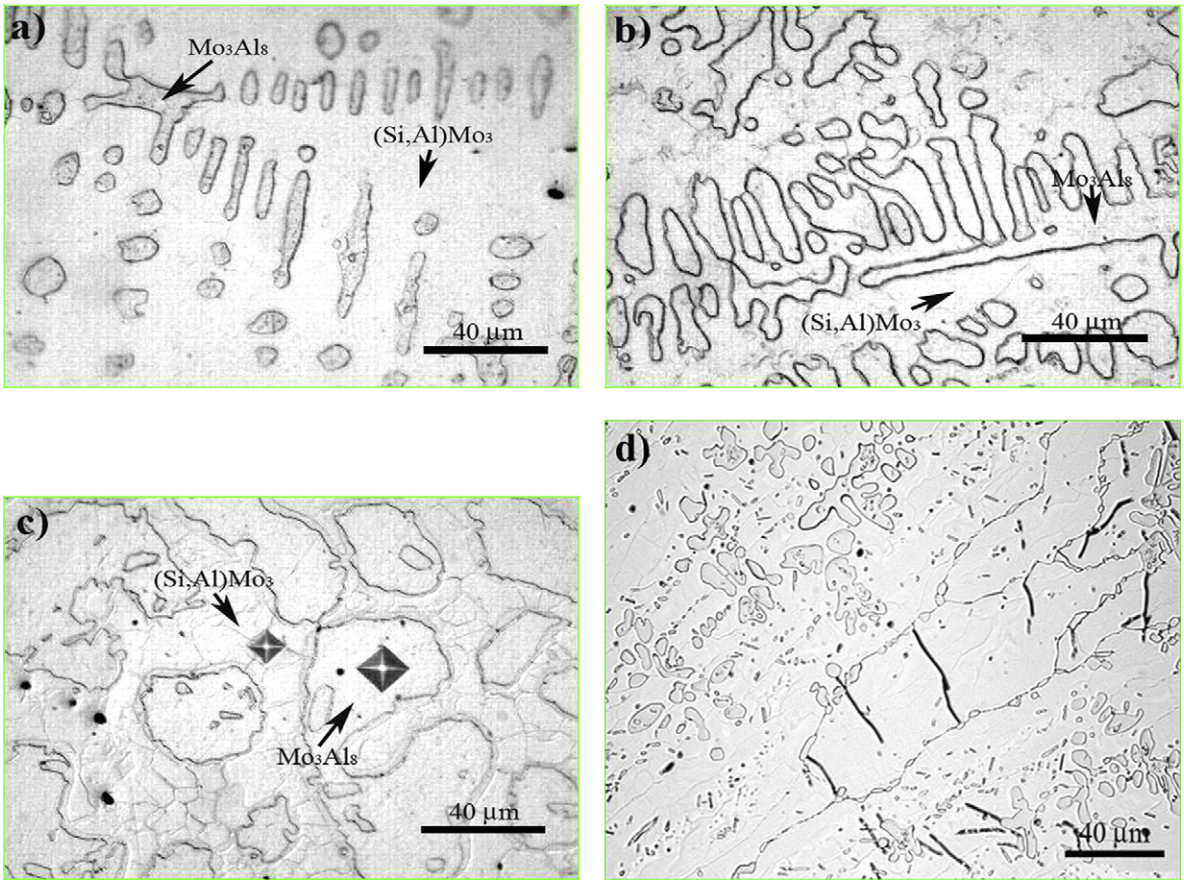

Fig. 1. (a) Microstructure of the sample with 8 at.% Al. (b) Microstructure of the sample with 12 at.% Al. (c) Microstructure of the sample with 16 at.% Al. (d) Surface of the compressed surface sample 8 at.% Al showing the crack trapping.