Journal of Materials Science and Nanomaterials

Patra, J Mater Sci Nanomater 2017, 1:1

Editorial OMICS International

Oxide Dispersion Strengthened High Temperature Alloys

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Received date: August 10, 2017; **Accepted date:** August 11, 2017; **Published date:** August 18, 2017

Introduction

Refractory grade alloys (W, Mo, Nb, Ta based) can be used in high temperature structural applications such as in defense, aerospace and nuclear industries owing to elevated melting temperature [1]. Fabrication of refractory materials from conventional microcrystalline powders requires significantly higher temperature for consolidation which causes significant grain growth and degrades the mechanical properties. Further some of the refractory metal such as W which is widely used as kinetic energy penetrator and plasma facing material in nuclear reactor also exhibit poor oxidation resistance at 1000°C temperature [2]. Therefore to improve the mechanical properties and subsequently the oxidation resistance alloying addition has been carried out (Ni, Ti, Fe, Cu) along with several dispersed oxides (Y_2O_3, La_2O_3, ThO_2) with nanometer particle size. Among all the oxides Y_2O_3 is majorly used as dispersion owing to high temperature stability.

The alloys are synthesized by mechanical alloying which includes rotating the powders and along with grinding balls and two third filled process control agent (toluene, stearic acid) in a container at about 300 rpm for a specific period of time to achieve nanostructured powders. Nanostructured powders possess enhanced surface are and substantially reduces the consolidation or sintering temperature. Addition of nano oxide dispersion in refractory powder blend hastens the particle refinement process. The added elements diffuses in the solvent phases by flattening, fracturing process of powder particles aided by intensive stress assisted deformation and finally results in alloying.

The nanostructured alloy powders are further consolidated by either pressure less or pressure assisted sintering process. The pressure less sintering process involves fabrication of pellets from alloy powder by pressure application in a hydraulic press followed by sintering with substantial period of soaking (1-2 h). In pressure assisted sintering method the pressure is applied along with sintering which has a significant impact on the density of the sintered alloys. The sintering is performed by application of spark discharges (spark plasma sintering) or hot pressing, hot isostatic pressing, hydrostatic extrusion. The heating rate in pressure less sintering varies 5-10°C/min, whereas in spark plasma sintering the heating rate is in the range of 50-300°C/min with minimal soaking time (5 min). Therefore chances of grain growth are considerably minimized. The sintering is carried out in hydrogen, argon of in vacuum environment to inhibit the oxidation of the sintered alloys. During pressure less sintering due to overall high sintering time (from heating to cooling time) the shrinkage rate of the alloys is also higher as compared to spark plasma sintering.

The sintering process is varied either as solid state sintering or liquid phase sintering. During solid state sintering particle neck formation, particle growth and finally particle rearrangement for pore closure required increased sintering temperature and time. Liquid phase sintering includes the presence of an elements having lower melting temperature than the sintering temperature. The lower melting point material starts melting prior to the attainment of the sintering temperature. The selection of lower melting element for liquid phase sintering is based on the solubility with respect to the base metal, liquidus temperature and thermodynamic stability [1].

The presence of dispersed oxide at the interface hinders the grain boundary migration, refines the grain size of the alloy. The dispersion strengthening is also influenced by the size, interparticle distance and volume fraction of the oxide particles. The reduction in the grain size increase the grain boundary area which can accumulate several defects including radiation based defects [3] and improves the elevated temperature strength, creep and resistance against radiation. The dispersion of oxide particles along the interface is supposed to be non-homogeneous which leads to variation in grain boundary movement and results in bimodal/multimodal grain size distribution. This type of size distribution is eventually beneficial in terms of achieving both higher strength and ductility [4]. The milling time, solubility of solvent element in parent matrix, sintering temperature and time is of vital importance to control the volume fraction of intermetallic phases formed during sintering. Addition of small weight fraction of dispersed Y_2O_3 oxide (1-2 wt %) can also be effective in improving the oxidation resistance by acting as a sink for voids, pores and minimizing the crack propagation during oxidation [5].

Much of the research on oxide dispersion strengthened (ODS) alloys is primarily focused on W based alloys to improve the strength, ductility and oxidation resistance. Recent literature also suggests improvement in ductility of ODS-Mo alloys [6]. Nb, Ta are also ductile in nature but their application at high temperature structural application is limited due to poor resistance to oxidation. The investigation of Nb-ODS and Ta-ODS alloys still need to be explored.

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